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ABSTRACT

This document contains the proceedings of the 2002 Annual International Conference of the Association for the Education of Teachers in Science which was held in Charlotte, North Carolina, January 10-13, 2002. Papers include: (1) "Teaching Science Methods Courses with Web-Enhanced Activities" (Alec M. Bodzin); (2) "How Is Your Lawnmower Working? Understanding Scientific Inquiry through Metaphors" (William S. Harwood, Rebecca R. Reiff, and Teddie Phillipson); (3) "Teacher Explanations for Discourse Variations in Elementary Science Methods" (William J. Newman Jr., Paula D. Hubbard, and Sandra K. Abell); (4) "Strategies Enabling Teachers to Critically Analyze Learning and Teaching" (Donna R. Sterling); (5) "A Quantitative Comparison of Instruction Format of Undergraduate Introductory Level Content Biology Courses: Traditional Lecture Approach vs. Inquiry Based for Education Majors" (Jennifer L. Willden, David T. Crowther, Alan A. Gubanich, and John R. Cannon); (6) "Examining the Influence of a Graduate Teaching Fellows Program on Teachers in Grades 7-12" (Stephen L. Thompson, Vicki Metzgar, Angelo Collins, Melvin D. Joeston, and Virginia Shepherd); (7) "Preservice Secondary Science Teacher Apprenticeship Experience with Scientists" (Sherri L. Brown, Kim Bolton, Nancy Chadwell, and Claudia T. Melear); (8) "Views of Science Teachers One-Three Years After a Pre-Service Inquiry-Based Research Course" (Leslie Suters, Claudia T. Melear, and Leslie G. Hickok); (9) "Evaluation of a Model for Supporting the Development of Elementary School Teachers' Science Content Knowledge" (Alicia C. Alonzo); (10) "Impacts of Contextual and Explicit Instruction on Preservice Elementary Teachers' Understandings of the Nature of Science" (Juanita Jo Matkins, Randy Bell, Karen Irving, Rebecca McNall); (11) "An Extended Examination of Preservice Elementary Teachers' Science Teaching Self- Efficacy" (Patricia D. Morrell and James B. Carroll); (12) "Science, Creationism and Religion: Responses from the Clergy" (Alan Colburn, Laura Henriques, and Michael Clough); (13) "A Card Sorting Task To Elicit Science Teaching Orientations" (Patricia J. Friedrichsen and Thomas M. Dana); (14) "Managing Student/Teacher Co-Construction of Visualizable Models in Large Group Discussion" (John Clement); (15) "Voices in a Reservation School: A Sonata-Form Narrative from

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a Professor and a Dakota Pre-Service Teacher about Their Professional and Practical Knowledge Teaching Science in Culturally Responsive Ways" (Jo Anne Ollerenshaw and Delberta Lyons); (16) "Discrepant Questioning as a Tool To Build Complex Mental Models of Respiration" (Mary Anne Rea-Ramirez and Maria C. Nunez-Oviedo); (17) "The Influence of a Philosophy of Science Course on Preservice Secondary Science Teachers' View of Nature of Science" (Fouad Abd-El-Khalick); (18) "Developing an Authentic Language for a Web-Searchable, Hypermedia Teacher-Education Database" (E. Barbara Klemm); (19) "Professional Development Models: A Comparison of Duration and Effect" (David T. Crowther and John R. Cannon); and (20) "Chemistry Students' Challenges in Using MBLs in Science Laboratories" (Hakan Yavuz Atar). (MVL)

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Proceedings of the
2002 Annual International Conference of the Association for the Education of Teachers in Science

Edited by:

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Preface

The editors are pleased to present the proceedings of the 2002 Annual International Conference of the Association for the Education of Teachers in Science, held in Charlotte, North Carolina, January 10-13, 2002. This is the seventh in the set of proceedings of AETS annual conferences. Over 70 papers and summaries of presentations from the conference are included. They are ordered by the corresponding conference session and then by the first author's last name. The conference program also is included for reference.

The papers and presentation summaries submitted for inclusion in the proceedings were reviewed by one of the four editors. They were not heavily edited and were not refereed, so they serve as a record of papers and presentation summaries from the 2002 AETS annual meeting.

These proceedings are disseminated via the ERIC Clearinghouse for Science, Mathematics and Environmental Education in microfiche form (with hard copy available through ERIC) and on the AETS World Wide Web Site at URL http://www.TheAETS.org. Given ERIC documents and web materials are not copyrighted, papers and presentation summaries included in these proceedings may be submitted for publications in journals such as the *Journal of Science Teacher Education* and *Science Education*. For information on how to secure a microfiche or hard copy of these proceedings through ERIC, see your campus or local library, WWW URL http://edrs.com/, or phone 800-433-ERIC. Also, the papers and presentation summaries included in these proceedings may be downloaded directly from the AETS WWW site as RTF (Rich Text Format) files.

We are very pleased to have had the opportunity to edit the seventh in the set of AETS annual conference proceedings.

Peter A. Rubba, The Pennsylvania State University
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Acknowledgment

The editors gratefully acknowledge the assistance of Nancy J. Thomas in helping to compile these proceedings and Bobbi Robison for placing them on the Web.

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2002 AETS Conference Program

Association for the Education of Teachers in Science, 2002 Annual International Conference, Charlotte, North Carolina, January 10-13, 2002.

AETS Annual Meeting 2002
Pre-Conference Workshops
8:30 -12:00 Noon
January 10, 2002

Workshop 1: Developing Inquiry-Based Science Materials: A Guide to Educators **Salon F & G**

The meaning of "curriculum in the context of planning, obtaining funding for, designing, staffing and carrying out effective development, implementation and assessment of instructional materials will be highlighted. The importance of teachers in any materials development effort will be discussed as part of the recommended role of teachers as academic leaders. Implications for changes in school organization and teacher education based on a "Continuous Improvement" approach will be discussed. Participant input will be solicited on plans for a professional development program for materials developers. The book will be provided to attendees and includes a summary guide to project development.

Presenters: *Herbert D. Thier*, Lawrence Hall of Science, University of California, Berkeley
Cost: $15

Workshop 2: Making Science Accessible and Inclusive: Strategies for Methods Courses, Teacher Professional Development and K-12 Classrooms **Salon A & B**

This interactive workshop provides participants with strategies and materials for use in methods courses and with experienced teachers for use in K – 12 classrooms. This workshop continues the efforts previous AETS sessions on inclusive science and the monthly up-dates provided on the AETS listserve. Strategies to support learning disabilities, physical modifications, and other characteristics that marginalize participation in the science community will be shared and demonstrated. Presenters will provide resources and materials for participants. Participants will also be asked to bring resources and materials that they have found useful in their practice.

Presenters: *Marcia Fetters*, Western Michigan University, *Dawn Pickard*, Oakland University, *Greg Stefanich*, University of Northern Iowa, *Eric Pyle*, West Virginia University

Cost $20

Workshop 3: Scholarly Writing for Science Teacher Educators **Salon C**

In our profession we are expected to communicate with our peers through our publications. Yet crafting a document that eloquently translates research into prose for teachers, colleagues, or peers is not an easy task. This workshop will explore basic elements of scholarly writing with the intent of enhancing participants' writing and publishing strategies.

Presenters: *Julie Luft*, Chair, AETS Publications Committee
Cost $10

Workshop 4: Creating a Web Site for your Science Methods Course **Elizabeth**

An effective and well-designed web site can be a powerful addition to any education course. This workshop, intended for beginners, will focus on web site design. Site layouts, key elements such as syllabus and on-line readings, page templates for consistency, using on-line data bases for discussion groups, ways to facilitate communication with supervising teachers, accessibility, and style tips will be covered. Student perspectives will be shared as well as student evaluations of an existing web site. Participates should bring a laptop and their own web authoring software. Participates will receive a CD-ROM with various templates.

Presenters: *Michael Svec and Alan Schuster*, Furman University
Cost $20

Program Highlights

- Thursday Featured speaker is James Randi, a world-renowned speaker about science versus pseudoscience, particularly when it applies to public understanding of science

- Thursday Get Involved in AETS interactive session.

- Thursday Giant Poster session, cash bar and hors d'oeuvres from 5:00 to 6:00

- Thursday Reception from 6:00 to 9:00 that features a Southern Reception Buffet, cash bar and entertainment by the *Band of Gold*, an oldies band playing your favorite tunes from the 1950's and 1960's.

- Friday Box lunch and AETS Committee meetings

- Friday Regional Meetings. Come and find out what is going on in your region.

- Friday The Best of Brahms presented by the Charlotte Symphony at the Bluementhal Center for the Performing Arts. (Need tickets)

- Saturday Awards Luncheon

- Saturday From 7:30 to 9:30, Women in Science get-together. (Need tickets)

Other Information

Check you program carefully as some sessions are double sessions. The time allotment for each session is next to the description of the session.

Thursday Afternoon
General Sessions
1:00 - 2:15 p.m.

Keynote Address: **Salon D**

Keynote Speaker: James Randi

James Randi is a world-renowned speaker about science versus pseudoscience, particularly when it applies to public understanding of science

2:15-2:30 p.m. **Coffee Break** **Pre-Function Area**

Thursday Afternoon
Concurrent Sessions
T 1
2:30 - 3:30 p.m.

2:30-3:30 p.m. **Panel Symposium (60 min)** **Myers Park**

Challenging Our Thinking and the Nature of Reform in Science Teacher Education: Implications for Policy in Science Education

This session focuses on how we can "make a difference" about science teacher education experiences in the context of reform and policy in science education.

Panelists: *Patricia Simmons*, University of Missouri-St. Louis

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2:30-3:30 p.m. **Interactive Session (60 min)** **Dilworth**

Scientific Literacy for All: Funding Scenarios in Urban Settings Serving Global Populations

Discussion of a master's program and funding strategies that promote scientific literacy in New York City. Electronic illustrations will be used to demonstrate program effectiveness.

Presenters: *Pamela Fraser-Abder*, New York University, *Nina Leonhardt*, Suffolk County Community College

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2:30-3:30 p.m. **Demonstration (60 min)** **Eastover**

Teaching Science Methods Courses With Web-Enhanced Activities

This session presents instructional approaches that utilize Web-based interactivities for learning science content and concepts in Lehigh University's elementary and secondary science methods courses.

Presenter: *Alec M. Bodzin*, Lehigh University

An Introduction to the Teacher Education Materials (TE-MAT) Database: An On-line Resource for Science and Mathematics Teacher Educators

Demonstration of a searchable on-line database of professional development materials for use with K-12 science/mathematics teachers, which contains descriptive and evaluative reviews and bibliographic information.

Presenters: *Kimberley Wood and Joan Pasley*, Horizon Research, Inc.

2:30-3:30 p.m. **Contributed Papers (60 min)** **Elizabeth**

Formative use of Select-And-Fill-In Concept Maps in Online instruction: Implications for Students of Different Learning Styles

How do students of different learning styles respond to online instruction in which SAFI maps are utilized? The purpose of the research was to investigate the formative use of SAFI maps in online instruction and effects their use may have on questions requiring application of knowledge. In particular, the implications of their use with students of different learning styles was considered. The subjects of the study were students enrolled in a ten week long, online environmental science course at a community college. This research used an emergent, collective case study design, each collective case consisting of students (within the course) who shared a dominant learning style as determined using Kolb's Learning Style Inventory (LSI-3).

Presenter: *Charles Kaminski,* Middlesex Community College

The Effects of Collaborative Concept Mapping on the Achievement, Science Self-efficacy and Attitude Toward Science of Female Eighth Grade Students

Although there has been extensive research into the uses of concept mapping in science education, few studies have sought to examine gender-related responses to the technique. This research was designed to address the growing antagonism of females to science, by exploring whether collaborative concept mapping, used frequently during the teaching of a middle school science program, would lead to changes in females' science self-efficacy and promote positive attitudes to science as well as enhancing their achievement.

Presenter: *Antoinette Ledger*, University of Massachusetts-Lowell

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2:30-3:30 p.m. **Contributed Papers (60 min)** **Wendover**

The Sisters in Science Program: Barriers Broken and Lessons Learned

Since 1994, the Sisters in Science Program has been created and implemented in urban elementary schools. Lessons learned and barriers broken will be described.

Presenters: *Penny L. Hammrich and Beverly Livingston,* Temple University, *Greer M. Richardson*, LaSalle University

Engaging a Larger Feedback Loop: Redesigning a Science Methods Course inLlight of Students and Community Needs

The Teacher-to-Teacher extended program has begun a systemic change inelementary science methods better integrating the course into the entire teacher education program.

Presenter: *Michael Svec and Denise Crockett*, Furman University

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2:30-3:30 p.m. **Contributed Papers (60 min)** **Salon C**

Motivating Introductory Biology Students

Paper will focus on the use of motivation theory and context-based learning in developing web modules for teaching biology.

Presenter: *Arthur L. Buikema, Jr.*, Virginia Tech

A Quantitative Comparison to Determine if Teaching Style Effects Learning in an Undergraduate Biology Course

This session will compare examination scores of a traditional undergraduate biology class (lecture-based) with an equivalent undergraduate biology course taught in a hands-on praxis.

Presenters: *Jennifer Willden, David T. Crowther, Alan Gubanich, John R. Cannon*, University of Nevada, Reno

2:30-3:30 p.m. **Contributed Papers (60 min)** **Salon B**

Teacher Explanations for Discourse Variations in Elementary Science Methods
Through the examination of discourse strategies in a methods course during two foci of instruction, science and pedagogy, the instructor explained her use of discourse types.

Presenters: *William J. Newman, Jr., Paula D. Hubbard,* Purdue University, *Sandra K. Abell,* University of Missouri, Cobia

How Is Your Lawnmower Working? Understanding Scientific Inquiry Through Metaphors
This paper discusses science faculty members' use of metaphors to describe scientific inquiry.

Presenters: *William S. Harwood, Rebecca Reiff, Teddie Phillipson,* Indiana University

2:30-3:30 p.m. **Contributed Papers (60 min)** **Salon A**

Fostering Reflection and Building Community for Novice Teachers
This proposal describes the findings, of a study to foster communities of practice that act as a bridge between pre-service and the initial years of practice.

Presenters: *Jonathan Singer and Mary Stylslinger,* University of South Carolina, *Ann C. Cunningham,* Wake Forest University

Strategies Enabling Teachers to Critically Analyze Learning and Teaching
This 4-year study identifies conceptual obstacles and enabling strategies for teachers in grades 4-12 to develop and implement standards-based science and mathematics learning and teaching.

Presenter: *Donna R. Sterling,* George Mason University

2:30-3:30 p.m. **Contributed Papers (60 min)** **Salon F**

Inquiry and World view of Practicing Urban Teachers
This paper presents an analysis of teachers' beliefs and worldviews in an effort to better understand and assist teachers in their own development.

Presenters: *Nancy Davis and Elizabeth Hancock,* Florida State University

The Effects of Participation in a Science Work Experience Program for Teachers: Shaping Professional Development Based on Follow-Up Data
Interviews and classroom observations of eleven participants document the effects of a Science Work Experience Program for Teachers in an effort to shape SWEPT efforts.

Presenter: *Wendy Michelle Frazier,* Old Dominion University

2:30-3:30 p.m. **AETS Session (60 min)** **Salon G**

Get Involved in AETS
For first time AETS Conference attendees, new members, and experienced members. Come and learn more about how to get involved in AETS, the organization, the conference, and how AETS operates.

Presenters: AETS Officers

Thursday Afternoon
Concurrent Sessions
T 2
3:40 - 4:40 p.m.

3:40-4:40 p.m. **Panel Symposium (60 min))** **Myers Park**

Predicaments and Possibilities: The Views of Four Urban Middle School Science Teachers
Hear the perspectives of urban teachers about the issues they face along with suggestions for how such information could be integrated into teacher preparatory programs.

Panelists: *John Settlage*, University of Utah, *Angela Terranova, Frances Perkins, Donald Jolly, Michael Killik*, Cleveland Municipal Schools

3:40-4:40 p.m. **Interactive Session (60 min)** **Dilworth**

Snails are Science: Creating Context for Science for Science Inquiry
The interactive session will demonstrate, examine and report the discoveries of a field study comparing the efficacy of two different teaching methods on two different groups of second-grade students experiencing two similar science inquiry lessons.

Presenters: *Christine D. Warner and Christopher Anderson*, The Ohio State University

3:40-4:40 p.m. **Demonstration (60 min)** **Eastover**

Is the Moon Only Out at Night?
Children's literature and textbook representations of the sun/moon system will be presented. Teaching strategies for the lunar phase cycle will be shared.

Presenter: *Kristin T. Rearden*, University of Tennessee

Development of an Elementary Earth Systems Science, Mathematics, and Technology Curricu
The development of an elementary earth systems science curricu that reflects diverse cultural perspectives will be presented. Using remote sensing technology, the curricu explores the relationship between seasonal changes and animal migration.

Presenters: *George Gleason*, Virginia Tech, *Jeff Frykhlom*, University of Colorado, *Lee Vierling*, South Dakota School of Mines and Technology

3:40-4:40 p.m. **Contributed Papers (60 min)** **Elizabeth**

Science Standards Survey: What Georgia's Elementary Teachers Tell Us
Survey results of inservice teachers about what they received and needed from their preservice preparation programs to be better.

Presenters: *Letty Bridges*, State University of West Georgia, *Genell Harris*, University of South Carolina, Spartenburg

The Conceptions and Actions of Participants in the Program for Alternative Certification in Secondary Science
This paper will present findings on the concepts of teaching and learning formed by the participants in one university's alternative certification program.

Presenters: *Thomas R. Koballa, Jr., Kim Nichols, Grace Lyon*, University of Georgia

3:40-4:40 p.m. **Contributed Papers (60 min)** **Wendover**

How do Preservice Teacher Ideas about Teaching Science Changeover the Course of a Secondary Science Methods Class?
Changes in preservice teachers conceptions of science teaching were explored over the duration of a secondary science methods course using pre and post concept maps.

Presenters: *Gill Roehrig and Julie A. Luft*, University of Arizona

Middle School Science Teachers' Preparedness to Teach Standards-based Light Concepts
The purpose of this study was to assess middle-school teachers' conceptual understanding of light concepts they might be expected to teach.

Presenters: *John E. Christopher and Ronald K. Atwood*, University of Kentucky, *Kathy Cabe Trundle*, Ohio State University

3:40-4:40 p.m. **Contributed Papers (60 min)** **Salon C**

"Why I Want to Be a Science Teacher" Autobiographical Paper: Longitudinal Case Studies of the Personal Histories Supporting Career Science Teachers
Past and present autobiographical papers of nineteen secondary science education graduates were studied for intrinsic rationales for entering and remaining in science teaching.

Presenter: *Charles J. Eick*, Auburn University

Development, Implementation and Evaluation of Student Attitudes toward the Use of Concept-Mapping Technology in a High School Biology Program
This proposal will provide the results of the first phase of research involving high school science attitudes related to concept mapping using Inspiration Software.

Presenters: *Nedra J. Davis*, California State University San Bernardino, *Mildred A. Hoover*, Apple Valley High School

3:40-4:40 p.m. **Contributed Papers (60 min)** **Salon B**

Science and Language Integration using Technology
Strategies for integrating science and language arts will be presented with examples from successful classroom applications. Implications for science teacher preparation will be discussed.

Presenters: *Lisa J. Libidinsky*, Pembroke Pines Charter School, *David D. Kumar*, Florida Atlantic University, *Clifford A. Hofwolt*, Vanderbilt University, *Amy Bingham*, Florida Atlantic University

3:40-4:40 p.m. **Contributed Papers (60 min)** **Salon A**

Examining the Influence of a School-Based Collaboration Involving Scientists and Science Teachers
This paper examines the influence on science teachers and students of participation in a school-based collaboration involving scientists and science teachers.

Presenter: *Stephen L.Thompson*, Vanderbilt University

3:40-4:40 p.m. **Contributed Papers (60 min)** **Salon F**

Preparing New Science Teachers to Accomplish the Vision of the National Science Education Standards: An STS Approach to Organizing a Secondary Science Methods Course
Results of the use of an STS approach to organizing a secondary science methods course and implications for preservice science teacher preparation will be discussed.

Presenter: *Pradeep M. Dass*, Appalachian State University

Thursday Afternoon
Poster Session
T 3

5:00 - 6:00 p.m. **Pre-Function Area**

Virtual Hands-On Experiences: The Use of Haptics in Students, Investigations of Viruses
This session features a new science tool, the nanoManipulator (nM) and describes how the ability to touch nanometer-sized materials impacts students, concepts.

Presenters: *M. Gail Jones, Dennis Kubasko, Russell M. Taylor II, Richard Superfine*, University of North Carolina at Chapel Hill, *Thomas Andre*, Iowa State University

TIGERS of a Different Stripe: Two-Way Professional Development Exchanges Between Middle Grades and Higher Education
This poster presentation will provide an overview of a K-12 Teaching Fellows Award in which middle grades mathematics and science teachers share their pedagogical expertise with graduate students in mathematics, science and engineering, who in turn bring their cutting-edge content to the teachers and their students.

Presenter: *Eric J. Pyle*, West Virginia University

Using Technology to Improve the Learning of Virginia Standards of Learning in Science
This investigation depicts the results of using technology as a means of instruction to meet the Virginia Standards of Learning (SOL) in high school. The results of the study indicate that technology can impact learning.

Presenters: *Richard J. Priest and Donna Sterling*, George Mason University

Teacher Professional Development Needs in Science, Mathematics, and Technology in Eastern North Carolina
The Center for Science, Mathematics, and Technology Education at East Carolina University surveyed Professional Development Liason teachers in Eastern North Carolina.

Presenter: *Rhea Miles*, East Carolina University

Case Method Approach in an Elementary Science Methods Course
The instructor will share her experiences using the case method in a pre-service elementary science methods course. Design, processes, and samples will be shared and feedback requested.

Presenter: *Judy Beck*, University of Wisconsin-La Crosse

Sun-Earth Connection Astronomy for Prospective and Beginning Teachers of Science
Astronomers, astronomy educators, and science teacher educators collaborate on undergraduate education, pre-service teacher preparation, and in-service teacher professional development to improve the teaching of sun-earth astronomy.

Presenters: *Kathleen A. O'Sullivan*, San Francisco State University, *Greg Schultz*, University of California

The Electronic Discussion Group as a Forum for Professional Development
Electronic discussion group entries from preservice and inservice teachers enrolled in a methods course were examined for evidence of professional growth within a proposed framework.

Presenter: *R. Paul Vellom*, Ohio State University

Eliciting Graduate and Undergraduate Science Education Students' Conceptions of the Nature of Science in Middle East Technical University (METU), in Ankara
This study elicits science education students' conceptions of the nature of science in a university in the city Ankara. The data have been collected through an open-ended questionnaire.

Presenters: *Bugrahan Yalvac and Barbara Crawford*, Pennsylvania State University

A Route to Teaching Reflection
In order to teach reflection, a tool has been created which guides preservice teachers toward the accumulation of a record of knowledge, affect and actions.

Presenters: *J. Steve Oliver and Carolyn Wallace*, University of Georgia

Progress Toward Equitable Systemic Reform in Five Middle Schools
The progress toward achieving equitable systemic reform in five schools that were part of an effort to reform science and mathematics education systemically is investigated.

Presenters: *Mary Kay Kelly and Jane Butler Kahle*, Miami University

The Monets of Methods Courses: Writing Impressionist Tales as Means of Reflecting on Beliefs and Knowledge about Science Teaching and Learning
We will present our use of impressionist tales (Van Maanen, 1988) as a tool for coaching reflection in elementary and middle grades science method courses.

Presenters: *Rachel Foster and Lynn A. Bryan*, University of Georgia

Investigating Consumer Science Products to Teach the Scientific Method
Investigating consumer products pre-service teachers are exposed to the scientific method and use these projects to develop integrated curricu units addressing state and national academic standards.

Presenters: *Jeff A. Thomas*, University of Southern Indiana

Preservice Science Teachers' Inconsistent Reflective Thinking On Subject-Matter Related Interview Projects
Preservice science teachers exhibited (topic-correlated) inconsistent reflective thinking, including differences when dealing with familiar versus unfamiliar science subject matter, while conducting interview projects.

Presenter: *Angela G. Cobb*, Cornell University

The Globe Program in Indigenous Classrooms in Northern Arizona
The GLOBE-NAN (Native American Network) Project provides professional development about the GLOBE Program with educators serving Native American students in northern Arizona. Preliminary findings of the project have implications for working with and promoting science education reform in indigenous communities.

Presenter: *Joelle Clark*, Northern Arizona University

Examination of student use of science conventions in investigating changes in habitats in the Everglades
This study analyzes science conventions used by elementary students who developed an authentic investigation of a habitat in the Everglades.

Presenters: *Scott P. Lewis and George E. O'Brien*, Florida International University

Thursday Evening
Reception

6:00 - 9:00 p.m. **Pre-Function Area**

50's Sock Hop Reception with *The Band of Gold*

Friday Morning

6:30-8:00 p.m. **Continental Breakfast** **Pre-Function Area**

Concurrent Sessions

F 1

8:00 - 9:00 a.m.

8:00-9:00 a.m. **Panel Symposium (60 min)** **Myers Park**

Contemporary Issues In Elementary Science Teacher Education
Several social and educational issues currently influencing elementary science teacher education will be explored within a context of ongoing elementary science teacher professional development.

Panelists: *Ken Appleton*, Central Queensland University, *Valarie Akerson*, Indiana University, *Brian Hand*, Iowa State University, *J. Randy McGinnis*, University of Maryland - College Park, *Katherine Wieseman*, Western State College, *Hedy Moscovici*, California State University-Dominquez Hills, *Janice Koch*, Hofstra University

8:00-10:10 a.m. **Panel Symposium (120 min)** **Dilworth**

Preservice Scientific Research Experiences
Longitudinal data on participants from two types of programs at two universities including how to start your own program in research for teachers from two scientists who did. The presentation will consist of four papers.

Presider: *Claudia T. Melear*, University of Tennessee

Views of Science Teachers One-Three Years After a Preservice Inquiry-Based Research Course
Presenters: *Leslie K. Suters, Claudia T. Melear, and Leslie G. Hickok*, University of Tennessee

The Transformative Experience of a Scientist Instructor with Teacher Candidates
Presenters: *Terry Lashley, Leslie G. Hickok, Claudia T. Melear*, University of Tennessee

Preservice Secondary Science Teachers Apprenticeship Experience with Scientists
Presenters: *Sherri L. Brown, Kim Bolton, Nancy Chadwell, Claudia T. Melear*, University of Tennessee

Providing an Astronomical Research Experience for Inservice and Preservice Teachers
Presenters: *John W. Wilson and Ed Lucy*, Georgia State University

8:00-10:10 a.m. **Interactive Session (120 min)** **Eastover**

Success Stories and Vignettes: Extending our Abilities as Elementary Science Teacher Educators
This interactive session spotlights best practice for the elementary science teacher educator. Written vignettes, available to the participants, will augment the traditional verbal sharing of teaching knowledge.

Presenters: *Gary Varrella*, George Mason University, *Caroline Beller*, University of Arkansas, *M. Jenice Goldston*, Kansas State University, *Cathy Yeotis*, Wichita State University, *Barbara Spector*, University of South Florida, *Patti Nason*, Stephen F. Austin State University

8:00-9:00 a.m. **Interactive Session (60 min)** **Elizabeth**

The Role of Teacher Learning Groups as Professional Development
Teacher learning/research groups, are analyzed as meaningful professional development, including iterative changes in practice and beliefs; trajectories of growth; and changes in school culture.

Presenter: *Karen Levitt*, Duquesne University, *Doris Ash*,, Universuty of California, Santa Cruz, *Sharon Beddard-Hess and Joseph Sciulli*, Asset Inc, *Windy Cheong*, San Francisco Unified School District, *Beth Kraft*, Novato School District

8:00-9:00 a.m. **Demonstration (60 min)** **Wendover**

Enhancing Environmental Science Experiences with Technology
Technologies are demonstrated that address NETS standards, while incorporating inquiry activities prior to, during and following a science methods class field trip.

Presenters: *Martha L. Schriver, Jacqueline Bedell, Ken Clark, Alice Hosticka*, Georgia Southern University

The Learning Matrix: A Peer Reviewed Online Learning Environment for Science and Mathematics Instructors at the College Level
This session will demonstrate the Learning Matrix website and explain how AETS members can collaborate in submitting and reviewing materials for online publication.

Presenters: *Kimberly S. Roempler and Judy Ridgway*, Eisenhower National Clearinghouse

8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon C**

Lessons Learned, Five Years of Science at INTASC
A discussion of the tensions and lessons learned over five years as standards, performance-based assessment and scoring were developed for beginning science teachers.

Presenter: *Angelo Collins*, Knowles Science Teaching Foundation

A Focus for Collaboration: Developing and Implementing Science and Mathematics Performance Assessment Tasks
This paper discusses the results of a partnership established to increase preservice and inservice teachers' understanding and experiences with performance assessment in mathematics and science.

Presenters: *Judith Morrison*, Washington State University, *Valarie Akerson*, Indiana University, *Amy Roth-McDuffie*, Washington State University

8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon B**

Teaching Ecology in Context
A description of a three-week sophomore level college ecology course taught in context by "bringing" a portion of the Serengeti to Virginia.

Presenter: *Arthur L. Buikema, Jr.*, Virginia Tech

Teachers' Understanding of Ecological Concepts
Elementary teachers were interviewed about their understandings of ecological concepts being taught to their elementary students, including how those concepts are revealed in everyday life.

Presenters: *Bruce Johnson and Jamie Carson*, University of Arizona, *James Kilbane*, Indiana Essential Schools

Network, *Duncan Martin*, Liverpool John Moores University, *Lars Wohlers*, Lueneburg University

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8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon A**

Technology's Tendency to Undermine Serious Study and Teaching
Technology often circumvents critical requirements of learning, hides or even inhibits students thinking, and may affect student and parents fundamental ideas about the purpose of schools.

Presenters: *Michael P. Clough and Joanne K. Olson*, Iowa State University

Technology Tools for Supporting Scientific Inquiry: A Pre-service Science Education Course
In a problem-based science course, prospective teachers work in technology-rich environments to build evidence-based arguments. Nature of science and metacognition are themes across the course.

Presenters: *Carla Zembal-Saul, Patricia Friedrichsen, Danusa Munford, Joe Taylor*, Pennsylvania State University

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8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon F**

Guiding Teachers' Research into Student Learning of Science
This presentation describes a design experiment in learning. Teachers systematically inquired into students' understanding of science to improve their learning and promote teacher professional development.

Presenter: *Frank E. Crawley*, East Carolina University

Reasonably Rich Environments in Professional Development Experiences in Scientific Inquiry
Project Mammoth Park is a professional development project that explicitly mirrors the science teaching that is called for in the reform in science education.

Presenter: *Edith S. Gummer*, Oregon State University

8:00-9:00 a.m. **AETS Session (60 min)** **Salon G**

Publishing in Science Education Journals
In this session, journal editors will discuss the focus of their journals, publishing tips for their journals, and suggestions for aspiring authors.

Presenters: Journal Editors from various Science Teacher Education Journals.

Friday Morning
Concurrent Sessions
F 2
9:10 - 10:10 a.m.

9:10-10:10 a.m. **Panel Symposium (60 min)** **Myers Park**

Getting to the Fourth Year: The Instruments and Protocols Used to Study the Practice of Beginning K-12 Science Teachers
Three presentations describing the instruments and protocols used in a three-year qualitative/quantitative study of over 90 beginning K-12 science teachers from across Minnesota.

Panelists: *George Davis and Alison Wallace*, Minnesota State University-Moorhead, *Patricia Simpson*, St.Cloud State University, *Bruce Johnson*, University of Arizona

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9:10-10:10 a.m. **Interactive Session (60 min)** **Elizabeth**

Immersion into Inquiry as a Strategy for Preservice Science Teacher Education
Inquiry is fundamental to the scientific enterprise and to good science teaching andlearning. However, many preservice teachers enter the teaching profession without ever experiencing inquiry beyond "hands-on" lessons for K-12 students. Join us in a standards-based 'immersion into inquiry' experience that is appropriate for preservice and inservice teachers alike

Presenter: *Nancy Landes*, BSCS

9:10-10:10 a.m. **Demonstration (60 min)** **Wendover**

The SOAR-High Project: An Innovative Science Program for Deaf Students
This presentation will focus on the innovative features and the evaluation of the SOAR-High Project, an on-line distance learning earth science experience for deaf students.

Presenter: *Charles R. Barman*, Indiana University Purdue University Indianapolis

Teaching Science to Students with High Incidence Disabilities
Teaching strategies and routines developed by the Center for Research on Learning for helping students with high-incidence disabilities develop conceptual understanding.

Presenters: *James D. Ellis and Janis Bulgren*, University of Kansas

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9:10-10:10 a.m. **Contributed Papers (60 min)** **Salon C**

Why are Dilutions Difficult for Students to Conceptualize?
This paper presents the findings of a study that addressed the issue as to why students have difficulty understanding dilutions.

Presenter: *Teddie Phillipson*, Indiana University

Evaluation of a Model for Supporting the Development of Elementary School Teachers' Science Content Knowledge
This presentation will describe and evaluate an inquiry-based professional development model for enhancing elementary school teachers' science content knowledge.

Presenter: *Alicia Cristina Alonzo*, University of California, Berkeley

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9:10-10:10 a.m. **Contributed Papers (60 min)** **Salon B**

Building Bridges: Using Science as a Tool to Teach Reading and Writing
This paper outlines the results of an action research conducted in a 5th grade classroom that integrated reading and writing instruction with hands-on science instruction.

Presenter: *Delna Nixon*, Washington State University

9:10-10:10 a.m. **Contributed Papers (60 min)** **Salon A**

Missing the Boat: A Closer Look at Preservice Elementary Teacher Beliefs About Science Teaching and Learning
This study compared beliefs about science teaching and learning of students who had taken a inquiry-based physics course prior to science methods to those who had not.

Presenters: *Paula Hubbard*, Purdue University, *Sandra Abell*, University of Missouri-Cobia

Instructional Challenges in Modeling Scientific Inquiry: The Case of Physics for Elementary Education
Is scientific inquiry an appropriate model for instructional inquiry? This question is examined in terms of the implementation of an inquiry-based physics course for elementary education majors.

Presenter: *Mark J. Volkmann*, University of Missouri

9:10-10:10 a.m. **Contributed Papers (60 min)** **Salon F**

The Development and Implementation of an Observational System for Hands-on Discovery Learning in Science
This study looks at the design and implementation of a classroom observational system designed to detect the presence of hand-on, discovery or inquiry instructional practices. The system is designed to be used with practicum and student teachers.

Presenter: *Clifford A. Hofwolt*, Vanderbilt University

Content Pedagogy Dilemma in Science Teacher Education: Implications for Policy and Practice
Pre-service teacher science competency issues will be addressed. How technology could bridge content and pedagogy will be discussed with implications for policy and practice.

Presenters: *David D. Kumar*, Florida Atlantic University, *Clifford A. Hofwolt*, Vanderbilt University

9:10-10:10 a.m. **Contributed Papers (60 min)** **Salon G**

Distance Education: Can We Provide Content Courses Via the WEB?
Describes our plan to export a popular course beyond classroom walls using real-time broadcast and two-way audio and video links to other classrooms. Some startup problems.

Presenters: *Bill Baird and Ralph Zee*, Auburn University

The Impact of an Online Computer Simulation on Teachers' Conceptions of Longitudinal Waves
This study demonstrates the effectiveness of using an innovative online simulation program to dispell student misconceptions about particle behavior in longitudinal waves

Presenters: *Karen Irving, Rebecca McNall, Joe Garofalo, Randy Bell,* University of Virginia

10:10-10:20 a.m. **Coffee Break**

Friday Morning
Concurrent Sessions
F 3
10:20 - 11:20 a.m.

10:20-11:20 a.m. **AETS Session (60 min)** **Myers Park**

AETS Town Meeting
An open forum to discuss issues related to AETS

Presiding: AETS Officers

10:20-11:20 a.m. **Interactive Session (60 min)** **Dilworth**

Use of Scientific Inquiry to Explain Counterintuitive Observations
To enhance process skills and content acquisition, structured exploration activities are used to explain counterintuitive observations. These developmentally appropriate activities draw students into the experiences.

Presenters: *Mary Jean Lynch and John J. Zenchak*, North Central College

10:20-11:20 a.m. **Demonstration (60 min)** **Eastover**

Teaching Controversial Issues of Bioethics
Participants will receive a copy of a jig-saw lesson on Genetically Engineered Foods, used in a methods course for analyzing a controversial current topic.

Presenter: *David R. Stronck*, California State University, Hayward

Ossabaw Island: Three Years of Teaming Technology with Outdoor Science to Meet the National Science Education and National Educational Technology Standards
For the past three summers, students in graduate level science education courses at the University of Tennessee have combined hands on science in the natural setting on Ossabaw Island with technology to meet National Science Education Standards, NCATE accreditation standards, and national Educational Technology Standards. The results are exciting.

Presenters: *Kathryn DiPietro*, University of Tennessee, *Becky Ashe*, West HighSchool

10:20-11:20 a.m. **Contributed Papers (60 min)** **Elizabeth**

An Extended Examination of Preservice Elementary Teachers' Science Teaching Self-Efficacy
Using the STEBI-B with undergraduate elementary teachers at various points in their preparation, significant differences in PSTE were found from methods instruction and student teaching experiences. Science content courses only affected the PSTE of those students who had low initial efficacy scores. STOE was unaffected.

Presenters: *Patricia D. Morrell and James D. Carroll*, University of Portland

Extension of the Self-Efficacy Beliefs About Equitable Science Teaching and Learning Instruments to include Learning Support and Gifted and Talented Students
The SEBEST -- assesses prospective elementary teacher self-efficacy beliefs toward science teaching and learning for diverse learners -- now includes learning support and gifted/talented students.

Presenters: *Jennifer Ritter*, Millersville University, *William J. Boone*, Indiana University, *Peter A. Rubba*, Penn

State University

10:20-11:20 a.m. Contributed Papers (60 min) Wendover

Measuring Scientific Reasoning Development: A Novel Approach
Dissatisfied with available instruments for measuring the scientific reasoning development of enrollees in contrasting styles of undergraduate introductory biology, we invented one that yielded intriguing insights.

Presenter: *Jeffery Weld*, University of Northern Iowa

Changing Teachers' Attitudes and Perceptions of Science and Scientific Research
The purpose of this qualitative study was to determine if a residential science research experience changed participants' attitudes and understanding of the nature of science.

Presenters: *Aimee L. Govett*, University of Nevada, *Debra Hemler*, Fairmont State College

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10:20-11:20 a.m. Contributed Papers (60 min) Salon C

Keiyo's (Kenya) Knowledge of Lizards and Chameleons
Keiyo language is unwritten. This study is documentation of Keiyo language of lizards and chameleons and is part of an ongoing study of Keiyo's biological knowledge, experiences, and science teaching and learning. Data is being used for development of indigenous curricu materials.

Presenter: *Norman Thomson*, University of Georgia

Basotho Students Perception of Topic Difficulty in Some Social-Related Concepts in Biology and Classroom Practices: Implications for Scientific Literacy.
This study tried to determine how Basotho students perceived genetics, social biology, ecology and microbiology topics. Most students perceived topics in genetics to be difficult.

Presenters: *E. O. Odubunmi and M. Tsepa*, Science Teachers Association of Nigeria

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10:20-11:20 a.m. Contributed Papers (60 min) Salon B

Integrating a Science Content Course and a Cognitive Development Course for Preservice Early Childhood Teachers: Barriers and Benefits
The session will analyze the process of integrating a science content course and a cognitive development course, including the perceived barriers and benefits.

Presenters: *April Dean Adams*, Northeastern State University, *Elizabeth Ethriddge*, University of South Florida at Sarasota-Manatee

We teach as We Were Taught: Integrating Active Learning and Pedagogy into Undergraduate Science Courses.
Local colleges collaborate to infuse pedagogy, cultural literacy, active learning,, and field experiences into science courses for future teachers. Data indicate success, with some challenges.

Presenters: *Donna L. Ross and Jeanne M. Weidner*, San Diego State University

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10:20-11:20 a.m. Contributed Papers (60 min) Salon A

A Scientific Method Based Upon Research Scientists' Conceptions of Scientific Inquiry
We suggest a scientific method that may bring greater clarity for teachers of science that reflects the conceptual

basis research scientists bring to their work.

Presenters: *William S. Harwood and Rebecca R. Reiff,* Indiana University

An Investigation of the Relationship Between Science Teaching Actions and Beliefs About the Nature of Science

A qualitative study on the secondary science teachers' science teaching actions with regard to their own beliefs about the nature of science.

Presenters: *Sajin Chun and J. Steve Oliver,* University of Georgia

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10:20-11:20 a.m. **Interactive Session (60 min)** **Salon F**

Collaborations for Success

Reorganization of professional systems [schools, departments, projects] from "Management ?By Objectives" [MBO] to "Continuous Improvement" [CI] is highlighted. Participate in interactive experiences that can change YOU professionally.

Presenter: *Herbert D. Their,* Lawrence Hall of Science, University of California, Berkeley

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10:20-11:20 a.m. **Interactive Session (60 min)** **Salon G**

GIS in Education

Geographic Information Systems (GIS) are making their way into classrooms across the continent. With ArcView or ArcVoyager GIS software from ESRI and free data from the Internet, teachers can explore the world. Students can incorporate data from a Global Positioning System (GPS) unit and explore their community, map their watershed, and analyze their planet. Participants will receive a free CD containing ArcVoyager Special Edition GIS software, lessons, and data.

Presenters: *ESRI Education Team*

Friday Morning
Committee Meeting & Box Lunch
F 4
11:40 a.m. - 1:00 p.m.

- Please pick up your box lunch in the **Pre-Function** Area prior to going to the Committee Meetings.

* Ticket, included in registration packet, is needed in order to pick up your lunch.

Elections Committee	**Dilworth**
Oversight	**Eastover**
Membership and Participation	**Elizabeth**
Awards	**Wendover**
Equity	**Salon C**
Professional Development	**Salon B**
Program (Conference Coordination)	**Myers Park**
Regional Unit Representatives	**Salon A**
Communications	**Salon F**
Publications	**Salon G**

Friday Afternoon
Concurrent Sessions
F 5
1:10 - 2:10 p.m.

1:10-2:10 p.m. Panel Symposium (60 min) Myers Park

Preparing Teachers Through Service Learning: Lessons from Case Studies
Discussion of some working models for placing perservice teachers in school settings prior to student teaching to provide early experience while assisting the community. Case studies and Outcomes.

Panelists: *Bill Baird and Charles Eick*, Auburn University

1:10-2:10 p.m. Panel Symposium (60 min) Dilworth

Preservice Teachers Experiencing Inquiry Through Scientific Research
This session will include pre-service teachers who have conducted scientific research, and will focus how it has impacted how they think about and teach science.

Panelists: *Penny J. Gilmer, Lori Hahn, Randy Spaid, Rebecca Brockwell*, Florida State University, *Ron Wark and Christy Tarter*, Escambia County Schools

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1:10-2:10 p.m. Interactive Session (60 min) Eastover

The 'how-tos" in the Creation of a National Professional Development Project.
A model for creation of a National professional development project that promotes scientific literacy through partnerships and a multiplier effect. NASA's "Mission to Mars" is the focus.

Presenters: *Robert K. James and H. Craig Wilson*, Texas A&M University

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1:10-2:10 p.m. Interactive Session (60 min) Elizabeth

Using a Card Sorting Task to Elicit Science Teaching Orientations
We will share a card sorting activity for eliciting science teaching orientations. This activity is designed to aid prospective teachers in articulating their teaching philosophies.

Presenters: *Patricia Friedrichsen and Thomas Dana*, Pennsylvania State University

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1:10-2:10 p.m. Interactive Session (60 min) Wendover

Building Visual/Spatial Thinking Skills in Children and Teachers
Visual/spatial thinking skills are fundamental to both professional science and to learning of science. Find out how to develop these skills in students and teachers.

Presenter: *Alan J. McCormack*, San Diege State University

1:10-2:10 p.m. **Demonstration (60 min)** **Salon C**

Helping Science Teachers Understand How Scientific Theory is Under Determined by Empirical Data
An important philosophical issue in the nature of science is that scientific theory is under determined by empirical data. Using the Learning Cycle, I demonstrate how the Full Option Science System (FOSS) "Humdingers" activity canbe used to introduce this important, abstract concept in the nature of science.

Presenter: *John R. Staver*, Kansas State University

Using Problem-Based Learning in an Elementary Science Methods Course
This demonstration will discuss how problem-based learning is used in my elementary science methods course to enhance the thinking of preservice teachers about science education issues.

Presenter: *James T. McDonald*, Purdue University

1:10-2:10 p.m. **Contributed Papers (60 min)** **Salon B**

Head Start on Science and Communication: A Content Based Literacy Development Program
The purpose of this presentation is to discuss a model that fosters science learning through a systematic approach to language development.

Presenters: *Penny L. Hammrich and Evelyn R. Klein*, Temple University

"On the Other Side of the Tracks"
The purpose of this paper is to describe the science education program in three academies of a middle school, the IB Program, Communication Academy, and School to Career Academy.

Presenter: *Felicia M. Moore*, Florida State University

1:10-2:10 p.m. **Contributed Papers (60 min)** **Salon A**

A Multicultural Comparison of Draw-A-Scientist Test Drawings of Eighth Graders
Drawings of scientists made by students from several different multicultural groups will be compared using the Draw-A-Scientist Test-Checklist.

Presenter: *Kevin D. Finson*, Western Illinois University

Science, Creationism & Religion: Responses from the Clergy
We will share results of a pilot study investigating how mainstream clergy reconcile creation stories and evolution. Implications for science teaching will be addressed.

Presenters: *Alan Colburn and Laura Henriques*, California State University-Long Beach, *Michael Clough*, Iowa State University

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1:10-2:10 p.m. **Contributed Papers (60 min)** **Salon F**

Explicit/Reflective Instructional Attention to Nature of Science and Scientific Inquiry: Impact on Student Learning
This study reports the impact of a professional development project on learning of nature of science and scientific inquiry for students in grades 6-12.

Presenters: *Renee S. Schwartz and Shiang-Yao Liu*, Oregon State University, *Norman G. Lederman, Rola Khishfe, Judith Sweeney Lederman, Lee Mathews*, Illinois Institute of Technolgy

Teaching Nature of Science: A Success Story
The purpose of this study was to investigate the effectiveness of an explicit inquiry- oriented compared to an implicit inquiry-oriented approach on students, understandings of NOS.

Presenters: *Rola Khishfe*, Illinois Institute of Technology, *Fouad Abd-El-Khalick*, University of Illinois at Urbana-Champaign

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1:10-2:10 p.m. Contributed Papers (60 min) Salon G

Bridging Content and Pedagogy within Early Childhood Teacher Preparation: Focusing on Children's Scientific Reasoning
Examines a redesigned early childhood program focused on preparing early childhood teachers to better support children's transition from intuitive theories to understanding formal subject matter.

Presenter: *Amy B. Palmeri*, Vanderbilt University

Social Interactions and Gender Differences Among Preschoolers Engaged in Science Activities
Findings from a two-year study focusing on the social interactions and gender differences among preschoolers (4-5 years old) engaging in science activities

Presenters: *Josephine M. Shireen Desouza*, Ball State University, *Charlene M. Czerniak*, University of Toledo

Friday Afternoon
Concurrent Sessions
F 6
2:20 - 3:20 p.m.

2:20-3:20 p.m. Interactive Session (60 min) Myers Park

Nurturing Inquiry in the Classroom: A Lesson Using Crystals
Participants will be introduced to redesigning a lesson on crystals, from STC's Rocks and Minerals module, to address specific content needs through an inquiry approach.

Presenters: *Barbara Manner*, Duquesne University, *Sharon Beddard-Hess*, ASSET Inc., *Argy Daskalskis*, Osborne Elementary School

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2:20-3:20 p.m. Interactive Session (60 min) Dilworth

Teacher-Student Co-Construction in Middle School Life Science
During the construction of intermediate mental models in life science, the teacher and students act like partners. They openly discuss their ideas and challenge each other's arguments.

Presenters: *Mary Anne Rea-Ramirez*, Hampshire College, *Helen Gibson*, Holyoke Public Schools, *Mary Jane Else*, *John Clement*, *Maria Nunez-Oviedo*, University of Massachusetts

2:20-3:20 p.m. Panel Symposium (60 min) Eastover

Reaching Out to Teachers: Is On-line Professional Development the Answer?
Educators with varying degrees of experience will discuss issues related to deliveringprofessional development to teachers using distance education technologies. Audience participation is encouraged.

Panelists: *Joan M. Whitworth*, Morehead State University, *Kathleen Davis and Morton Sternheim*, University of Massachusetts- Amherst, *Susan J. Doubler*, Lesley University, *Fredrick D. Siewers*, Western Kentucky University, *Chris Emery*, Amherst Regional High School, *Steve Murray*, Lawrence School

2:20-3:20 p.m. Demonstration (60 min) Elizabeth

Developing Pedagogical Content Knowledge (PCK) in a Science Methods Course
This presentation provides assignments including strand maps, video analyses and text evaluations to enhance the student understanding of PCK, its value, and a set of tools to use in enhancing their own PCK..

Presenter: *Patricia Simpson*, St. Cloud State University

Constructing Science Understanding in a Simulation-Based Environment
A presentation of computer simulation based instruction for constructing science understanding and its effect on teacher content knowledge.

Presenters: *David D. Kumar*, Florida Atlantic University, *Karen Tobias*, Broward County School District

2:20-3:20 p.m. Contributed Papers (60 min) Wendover

Tele-collaboration and Elementary Preservice Teachers Equals Benefits for Science Education
TEACH, a 2-year tele-collaborative project, led to improvement in the treatment groups both in aspects of technology and in aspects of science education reform.

Presenters: *Juanita Jo Matkins*, University of Virginia, *Elizabeth Klein*, State University of New York-Courtland, *Starlin Weaver*, Salisbury State University

K-12 Principals' Perceptions: Reforming Science Teaching
both qualitative and quantitative methods,this study explores principals' perceptions of various elements in science reform, specifically science teaching and school climate for professional development.

Presenters: *Stephen Marlette and M. Jenice Goldston*, Kansas State University

2:20-3:20 p.m. Contributed Papers (60 min) Salon C

Cleveland's Urban Fellows: A Master's Program for Cultivating Instructional Leaders in Urban Middle School Math and Science Teaching
The session relates this collaborative between an urban school system and the local state university involving thirty exemplary mathematics and science teachers.

Presenters: *Darlene Davies*, Cleveland State University, *Lorene France*, University of Akron, *John Settlage*, University of Utah

Assessing the Current and Projecting the Future of Urban Science Teacher Preparation
Twenty science educators whose institutions are major suppliers of urban teachers participated in a Delphi study. Issues addressed included useful resources, experiences and professional development.

Presenters: *John Settlage*, University of Utah, *Matthew Teare*, Cleveland State University

2:20-3:20 p.m. **Contributed Papers (60 min)** **Salon B**

Developing a Physics Course for Elementary & Middle Level Education Majors: Evolution of One Teacher's Enacted Curricu
Presenters will share the findings from a collaborative study engaging a physics professor and science educator in examining the enacted curricu of a physics course for prospective elementary and middle level teachers.

Presenter: *Carol Briscoe and Chandra S, Prayaga*, University of West Florida

Elementary Science Methods: Good Class Gone Bad
A case study highlighting critical incidents changing the climate in a methods class from risk free to tension dominated and emergent issues will be discussed.

Presenters: *Barbara S. Spector and Ruth S. Burkett*, University of South Florida

2:20-3:20 p.m. **Contributed Papers (60 min)** **Salon A**

Making Puerto Rican High School Physics Contextual and Culturally Relevant: A Statistical Analysis of Influencing Factors
Puerto Rican physics teachers' use of local examples, problems, and application of physics concepts in high school curricula and factors that influence their actions.

Presenters: *Wilson J. Gonzalez-Espada and J. Steve Oliver*, University of Georgia

Voices in a Reservation School: A Sonata-Form Narrative from a Professor and a Dakota Preservice Teacher about their Professional and Practical Knowledge Teaching Science in Culturally Responsive Ways.
Federally funded research yields divergent perspectives on teaching sciencein culturally responsive ways. Results from a narrative study will bepresented as an Umonhon Worldview.

Presenters: *Jo Anne Ollerenshaw and Delberta Lyons*, University of Nebraska -Lincoln

2:20-3:20 p.m. **Contributed Papers (60 min)** **Salon F**

A Comparison of Two Innovative Alternative Programs in Science Teacher Preparation
In response to the critical need for licensed science educators, Pacific University has developed two innovative programs. The design framework, course sequences, target audiences, and successes/issues within each program will be described.

Presenters: *Camille L. Wainwright and Mark Latz*, Pacific University

An Alternative Master's Degree and Certification Program for Potential Science Teachers
The M.Ed. with certification and emphasis in science education program was developed for potential teachers with a science background. The program, the rationale for the program design, and preliminary data on the students will be discussed.

Presenters: *Julie A. Luft, Willis Horak, Barbara Austin*, University of Arizona

2:20-3:20 p.m. **Demonstration (60 min)** **Salon G**

The Secret Life of the Brain
AETS is a partner in the outreach for this upcoming PBS series. Come and view the introduction of this series and the educational materials associated with the series.

Presenter: *Paricia McGann*, Channel 13/WNET, New York

3:20-3:45 p.m. **Coffee Break**

Friday Afternoon
Regional Meetings
3:45- 4:15 p.m.

Now that you have had some refreshment, meet with your regional AETS group and get involved. The regional meetings are in the following locations:

Northwest	**Myers Park**
North Central	**Dilworth**
Northeast	**Eastover**
Southwest	**Elizabeth**
Southeast	**Wendover**
Far West	**Salon A**
Mid Atlantic	**Salon B**

Friday Afternoon
Concurrent Sessions
F 7
4:15 - 5:15 p.m.

4:15 - 5:15 p.m. **Panel Symposium (60 min)** **Myers Park**

Distance Education Approach to Science Education Reform: Achieving Local Systemic Change in Small, Isolated School Districts
This symposium addresses the organizational, practical, and logistical considerations of effecting science education reform in small, rural, isolated school districts utilizing distance educational strategies and information technologies (regional workshops, local pro-D meetings, ITV sessions, and Internet communication).

Panelists: *Larry Yore*, University of Victoria, *James Shymansky and Len Annetta*, University of Missouri-St. Louis, *Joanne Olson and Brian Hand*, Iowa State University, *Susan Everett and Chia-Jung Chung*, University of Iowa

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4:15 - 5:15 p.m. **Demonstration(60 min)** **Dilworth**

Data Collection Everywhere--with Vernier LabPro®
Learn how you can collect data using the exciting Vernier LabPro® - the versatile interface that can be connected to a computer or a TI Graphing Calculator.

Presenter: *Gerard Ezcurra*, Vernier Software and Technology

4:15 - 5:15 p.m. **Interactive Session (60 min)** **Eastover**

Sheltered English in the Elementary Science Classroom: A Demonstration Lesson and Discussion
This session will entail a demonstration science lesson for a first grade classroom that employs Sheltered English techniques to increase comprehension for second language learners.

Presenter: *Gilbert Valadez*, California State University, San Marcos

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4:15 - 5:15 p.m. **Contributed Papers (60 min)** **Elizabeth**

The Nature and History of Science in 9th Grade Physical Science
An action research study emphasized explicit instruction in the Nature and History of Science. Questionnaires, interviews, and reflection provide argument for effectiveness of approach.

Presenters: *James Spellman and J. Steve Oliver*, University of Georgia

The Influence of a Philosophy of Science Course on Preservice Secondary Science Teachers, Views of Nature of Science
This study assessed the influence of a philosophy of science course on preservice secondary science teachers, views of, and perceptions of teaching about nature of science.
Presenter: *Fouad Abd-El-Khalick*, University of Illinois at Urbana-Champaign

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4:15 - 5:15 p.m. **Contributed Papers (60 min)** **Wendover**

Perspectives on Science Teacher Preparation
This presentation will reflect on current teacher preparation practices and will suggest new ways for preparing science teachers at all levels.

Presenter: *Marvin Druger*, Syracuse University

Professional Development for Elementary Science Teaches: Implications for Practice
This presentation describes a professional development for elementary teachers in science instruction. A model will be provided for implementing quality professional development activities.

Presenters: *Jerry Whitworth, Jeff Arrington, Patricia Hernandez*, Abilene Christian University

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4:15 - 5:15 p.m. **Contributed Papers (60 min)** **Salon C**

Preparing Science Specific Mentors: A Look at One Successful Georgia Program
Session paper focuses on the components of a successful mentoring program for science teachers, including participating teachers' views of the program.

Presenters: *Leslie Upson and Thomas Koballa*, University of Georgia, *Brian Gerber*, Valdosta State University, *Dava Coleman*, Cedar Shoals High School, *Baba Abayomi*, Albany State University

Novice Teachers' and Mentors' Perceptions of a Multifaceted Mentoring Program and the Needs of Early-Career Science Teachers
The perceptions of the participants in a collaborative program that provides support for new science teachers and their mentors are discussed and recommendations made.

Presenters: *Carolyn Dawson*, Northern Michigan University

4:15 - 5:15 p.m. **Contributed Papers (60 min)** **Salon B**

Developing an Authentic Language for a Web-Searchable, Hypermedia Teacher Education Database
We describe development of an authentic conceptual language for construction of a Web-based, searchable teacher education database for multi-media, hyperlinked standards- and research-based best practices.

Presenter: *E. Barbara Klemm*, University of Hawaii

Using a Web-Based Task to Make Prospective Elementary Teachers' Personal Theorizing About Science Teaching Explicit
This qualitative case study examines prospective elementary teachers' developing personal theories about science teaching and learning as revealed through a web-based task.

Presenters: *Carla Zembal-Saul and Lucy Avraamidou*, Pennsylvania State University

4:15 - 5:15 p.m. **Contributed Papers (60 min)** **Salon A**

Project ICAN: A Professional Development Program for Teachers' Knowledge and Pedagogy of Nature of Science and Scientific Inquiry
Project ICAN is designed to enhance middle and secondary teachers' disciplinary and padagogial knowledge related to nature of science and scientific inquiry. Project design and effectiveness are discussed.

Presenters: *Norman G. Lederman, Rola Khishfe, Judith Sweeney Lederman, Lee Mathews*, Illinois Institute of Technology, *Shiang-Yao Liu*, Oregon State University

The Science of Inquiry
Presents analysis of a professional development program in which teachers (K-12) develop a model for inquiry-based teaching through concurrent experiences in science research and reflective practice.

Presenters: *Jeff Dutrow, Maggie Helly, Nancy Davis*, Florida State University

4:15 - 5:15 p.m. **Contributed Papers (60 min)** **Salon F**

Teachers Inquire: Learning about Chemistry Education in a Master of Chemistry Education Program
We report the intended and enacted curricu of a Masters of Chemistry Education degree. Two participant-teachers' case studies illustrate the implementation of the learned curricu.

Presenters: *Catherine Milne*, University of Pennsylvania, *Matthew Corcoran*, Framingham High School, *Tracey Otieno*, Furness High School

Curricu by Design: Improving Student Leaning in College Chemistry and Biology
A curricu design model was developed and employed to create a focused and coherent curricu for first-year Chemistry and Biology college courses.

Presenters: *Robert Bleicher and Nancy Romance*, Florida Atlantic University

4:15 - 5:45 p.m. **Combined Panel and Poster Session (90 min)** **Salon G&H**

Preservice Elementary Education Program Innovations
A combined panel discussion and poster session will explore program innovations to support preservice elementary science teacher preparation.

Moderator: *Michael Kamen*, Auburn University

Panel Discussion

Unique Needs of Elementary Science Teachers
Mark D. Guy, University of North Dakota

The Nuts and Bolts Issues of Programmatic Innovations in Programs of Study for Prospective Elementary Teachers of Science (and Mathematics)
J. Randy McGinnis, University of Maryland

Issues Relating to Theory and Practice in a Constructivist Paradigm
Val Olness, Augustana College
Collaborations Between College of Education and College of Science Faculty in Order to Facilitate Elementary Science Education
April Dean Adams, Northeastern State University

State Requirements: The Good, the Bad, and the Ugly
Valarie Akerson, Indiana University

Poster Presentations

Integrated Internships
Michael Kamen and Kimberly Lott, Auburn University

Technology Tools to Support Teaching and Learning
Mark D. Guy, University of North Dakota

Maryland Collaborative for Teacher Preparation
J. Randy McGinnis, University of Maryland

The New Basics Project
John Stir, Griffith University

Integrating Science Methods with Reading, Mathematics, Art and Music Methods Through Common Field Experiences and Assessment Methods
Michael R. Cohen, Indiana University Purdue University Indianapolis

The "Urban Semester"
Melissa A. Mitchell, Ball State University

Meeting the Needs of Preservice Elementary Teachers in Science Content Courses
Carolyn Dawson, Northern Michigan University

Interdisciplinary Approaches to Curricu Design
Katherine C. Wieseman, Western State College

Teaching in the Constructivist Paradigm
Val Olness, Augustana College

Color Coding Analysis Strategies for Inquiry Based Science Teaching and Learning
Kathryn A. Ahern, Hofstra University

Content Course for Education Majors
April Dean Adams, Northeastern State University

Restructuring for Licensure
Patricia Paulson, Bethel College

Specialized Studies in Aviation Course for Elementary Education Majors
Christine Mosely, Oklahoma State University

Performance Assessment in Science Methods
Valarie Akerson, Indiana University, *Judith A. Morrison and Amy Roth-MdDuffie*, Washington State University

Using Web Based Portfolios to Assess Preservice Science Teachers
Alec M. Bodzin, Lehigh University

Saturday Morning

6:30-8:00 p.m. **Continental Breakfast** **Pre-Function Area**

Concurrent Sessions

S 1

8:00 - 9:00 a.m.

8:00-9:00 a.m. **Panel Symposium (60 min)** **Myers Park**

Science Faculty Members' Conceptions of Scientific Inquiry: Insights from the Frontlines of Science
This panel symposium will be comprised of three investigators who will describe how scientists understand scientific inquiry.

Panelists: *William S. Harwood, Rebecca Reiff, Teddie Phillipson*, Indiana University

8:00-10:00 a.m. **Panel Symposium (120 min)** **Salon G&H**

Science Education in California

This session focuses on science education in California. Presenters will discuss science education programs, science/science methods courses, research, policies and politics, and the California Science Teachers Association.

Moderator: *Kathy Norman*, California State University, San Marcos

TEACHER PREPARATION PROGRAMS
Integrating Science, Cultural Literacy, and Pedagogy: An Innovative Approach in California's Return to Undergraduate Credential Programs.

Professional Development Opportunities for Preservice Science Teachers

Update on the Pathways to Professionalism Intern Program at CSUSB for Multiple Subject Candidates - Program and Assessment

Including the Free Activities Guides of Project WILD and Project Learning Tree within the Methods Courses for Teachers

Inspiring Creative Thinking and Innovativeness in Prospective Elementary Teachers - Project SPARK

"A Head Start on Science" Project at California State University, Long Beach

PROGRAMS FOR PRESERVICE AND PRACTICING TEACHERS
The Fresno Collaborative for Excellence in the Preparation of Teachers (FCEPT)

PROGRAMS FOR PRACTICING TEACHERS
California Science Teachers Association: Professional Development

Inquiry, Cultural literacy, and Informal Science Education Share the Spotlight: Lessons from the Development of a New M.A. degree in Science Education.

Graduate Opportunities for Teachers in North County San Diego: A Masters in Education Degree Integrating Science, Mathematics and Educational Technology

RESEARCH ON TEACHING
Using the Research on Teacher Wisdom to Identify Learning Outcomes for Science Teacher Credential and Masters Degree Candidates

Secondary Science Emergency Permit Teachers' Perspectives on Power Relations in their Environments and the Effects of these Powers on Classroom Practices

SUMMARY: SCIENCE EDUCATION IN THE GOLDEN STATE
The Science Instructional Setting in California: Politics, Policies and Potential

Presenters: *Kathy Norman*, California State University, San Marcos, *David M. Andrews*, California State University, Fresno, *Bonnie Brunkhorst, Herbert Brunkhorst, Jan Woerner*, California State University, San Bernardino, *Alan Colburn, Laura Henriques, William C. Ritz*, California State University, Long Beach, *Cheryl Mason*, National Science Foundation, *Alan McCormack and Donna L. Ross*, San Diego State University, *Hedy Moscovici*, California State University, Dominquez Hills, *David R. Stronck*, California State University, Hayward, *William F. McComas and Diana Y. Takenaga-Taga*, University of Southern California

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8:00-9:00 a.m. **Interactive Session (60 min)** **Eastover**

Strategies for Getting a Faculty Position
This session will discuss potential higher education positions and typical responsibilities based upon 2000-01 listing. Suggestions for a successful job interview strategies plus professional acctivities that facilitate tenure.

Presenter: *Lloyd H. Barrow*, University of Missouri

8:00-9:00 a.m. **Interactive Session (60 min)** **Elizabeth**

The Science of Writing, the Writing of Science
The theory and practice of various genres of science writing using results from three empirical studies of preservice teachers and elementary students.
Presenters: *Christopher Andersen and Christine D. Warner*, Ohio State University, *Merce Garcia-Mila and Nubia E. Rojo*, Universitat de Barcelona

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8:00-9:00 a.m. **Interactive Session (60 min)** **Wendover**

Analyzing Instruction Materials: Teaching Pre-service Teachers to Recognize Inquiry
In this interactive session we will demonstrate a process for analyzing instructional materials from an inquiry perspective that can be used to affect pre-service teachers' understanding of inquiry. By using rubrics that emphasize the National Science Education Standards for Inquiry to analyze instructional materials, pre-service teachers develop a better understanding of inquiry and as a result, better understand the roles of instructional materials, teachers, and learners when facilitating inquiry in the classroom.

Presenter: *Janet Carson Powell and Jerry Saunders*, BSCS

8:00-9:00 a.m. **Demonstration (60 min)** **Salon C**

Interactive Internet Activities: Tools for Inquiry and Pathways to Reform
There is good reason to believe that interactive Internet science education utilities can be used to facilitate inquiry and promote educational reforms congruent with those envisioned in the National Science Education Standards. Two types of Internet sites appear especially promising, those that offer simulations of research equipment or settings and those that allow students to interact with large relevant data sets will be demonstrated and discussed during this session.

Presenter: *Richard A. Huber*, University of North Carolina-Wilmington

Petals Around the Roses
"Petals Around the Roses," provides a way of allowing students to experience the process of self-regulation and the subsequent "Ah-ha!" experience

Presenter: *Robert L. Hartshorn*, University of Tennessee at Martin

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8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon B**

Are Elementary Science Methods Courses Preparing Teachers to Address the National Science Education Standards?
An investigation of a national sample of elementary science methods courses: their similarities, differences, and extend their design addresses the National Science Education Standards.

Presenter: *Leigh Smith*, University of Utah

Preservice Elementary School Teachers' Understandings of Theory Based Science Education
We examined student's understandings of the learning cycle. Results indicate students demonstrated understanding of each phase of the learning cycle after completing the two course sequence.

Presenters: *Ed Marek, Tim Laubach, Jon Pedersen*, University of Oklahoma

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8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon A**

Multiple Problems--Multiple Perspectives: Initiating a Science Professional Development School
Science Professional Development Schools have potential for enhanced development for science teachers, both prospective and practicing. Challenges and benefits will be examined in scholarly perspective.

Presenters: *Barbara A. Crawford and Sherry Kramer*, Pennsylvania State University

Professional Development for Inservice Teachers and Principals
A comprehensive review of literature is overviewed to identify what costitutes professional development for in-service teachers and principals and t he quality of professional development activities.

Presenters: *Nihal Buldu and Ozgul Yimalz*, Indiana University

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8:00-9:00 a.m. **Contributed Papers (60 min)** **Salon F**

Using Internal Evaluation in Curricu Development
Through the internal evaluation of a Chemistry Education degree we identify major themes in chemistry content courses that informed curricu development and implementation.

Presenters: *Catherine Milne*, University of Pennsylvania, *Matthew Corcoran*, Framingham High School

Creating a Curricu Community of Practice
This paper examines the formation of a curricu community of practice that includes teachers, educators, and scientists.
Presenter: *Leanne M. Avery*, Cornell University

8:00-9:00 a.m. **Poster Presentaion (60 min)** **Pre-Function Area**

Community Agency Field Experiences Followed by Co-Teaching in the Urban Community
Twelve preservice science teachers were placed in community agencies as a part of their initial field experience. All were then placed in four urban schools in cohort groups for their internship.

Presenters: *Becky Ashe*, West High School, *Claudia T. Melear*, *Leslie Suters*, *Sherri Brown*, University of Tennessee

An Examination of the Urban School Systems Efforts to Hire New Science Teachers
Fifty urban school systems were contacted to determine various dimension of their new teacher hiring procedures: sources, interview process, and demographic factors.

Presenter: *John Settlage*, University of Utah

Reaching a New Audience--Urban Teens in Museums
Presents findings about a program in which students from urban high schools participated in a museum-based project held during two-week sessions betweenschool terms.

Presenter: *Jim Kisiel*, Natural History Museum of Los Angles County

Humor as a Component of Science Classroom Environments: Teacher Practices and Student Perceptions in Urban and Multiculturally Diverse Classrooms
A survey administered to middle school teachers and students assessed the effectiveness of humor as an instructional and managerial tool in science classrooms.

Presenter: *Kathy Manning*, Cleveland State University

The Learning Corridor: Exploring an Urban Magnet School Initiative
This qualitative case study will explore and describe an urban, inter-district magnet school recently opened at the Learning Corridor in Hartford, Connecticut.

Presenter: *David Moss*, University of Connecticut

Community-Connected Science Education: Creating a Museum High School for Southwestern Virginia
Challenges in educating students for democratic citizenship are multiplying, while Lemke argues traditional science education is obsolete. In 2002 a new high school in Roanoke, VA - a 'museum school' - will address challenges with a learner-centered, community-connected curricu.

Presenter: *Michael L. Bentley*, Roanoke Higher Education Center

Without walls: The Science Classroom for Elementary Students in a Small Rural Village in Southern Mexico.
I looked at the science experiences of elementary students in a rural one-room school (una unitaria) in Southern Mexico.

Presenter: *James B. Calkin*, University of Georgia

Saturday Morning
Concurrent Sessions
S 2
9:15 - 10:15 a.m.

9:15-10:15 a.m. **Panel Symposium (60 min)** **Myers Park**

Legislative Challenges to the Teaching of Evolution: The Science Educators Response
State legislative sessions of 2001 presented challenges to science educators regarding teaching evolution. What are the responses from science educators to these political efforts?

Panelists: *Michael Wavering*, University of Arkansas, *Don Duggan-Haas*, Cornell University

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9:15-10:15 a.m. **Interactive Poster Session (60 min)** **Eastover**

Innovative Curricu Strategies Using Visualizable Mental Models in Middle School Life Science
Four innovative strategies based on intensive research and classroom testing will be presented with examples of training for the teachers and of actual classroom use.

Presenters: *Mary Anne Rea-Ramirez*, Hampshire College, *Helen Gibson*, Holyoke Public Schools. *Mary Jane Else and John Clement*, University of Massachusetts

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9:15-10:15 a.m. **Interactive Session (60 min)** **Elizabeth**

Relating the Natures of Science and Knowledge to Models and Model-Building
Engagement in activities and discussions to develop an understanding of the nature of knowledge, learning and science through understanding of models and model-building.

Presenter: *Steve Gilbert*, Virginia Tech

9:15-10:15 a.m. **Interactive Session (60 min)** **Wendover**

Infusing Inquiry into Science Methods Courses: Three Perspectives and Strategies
How do science teacher educators model inquiry in their methods courses? This session starts a conversation about practices of infusing inquiry into methods courses.

Presenters: *Marcia Fetters*, Western Michigan University, *Mark Templin and Janet Struble*, University of Toledo

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9:15-10:15 a.m. **Demonstration (60 min)** **Salon C**

Learning about Science Inquiry in the Context of an Innovative Life Science Course Designed for Prospective Elementary Teachers
This innovative life science course engaged prospective elementary teachers in an original science investigation as well as provided opportunities to teach elementary children.

Presenter: *Leigh A. Haefner*, North Carolina State University

Employing Case-based Pedagogy within a Reflection Orientation to Science Teacher Preparation
We will examine the use of case-based pedagogy (specifically, cases-as-layered-commentary and video cases) as an alternative professional development model that is grounded in a reflection orientation to teacher education.

Presenters: *Lynn Bryan and Deborah Tippins*, University of Georgia

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9:15-10:15 a.m. **Contributed Papers (60 min)** **Salon B**

Technology Use and Knowledge: A Survey of Science Educators
A survey of science educator's technology usage and needs were examined. Differences between current and desired levels of knowledge about using technology will be reported.

Presenters: *A. Louis Odom*, University of Missouri-Kansas City, *Jon E. Pedersen*, University of Oklahoma, *John Settlage*, University of Utah

Integrating Technology into the Classroom: Training the Teacher
The results of a one-day workshop on teacher learning indicated that it provided the basic skills and tools of the software but not with classroom integration.

Saturday Morning
Concurrent Sessions
S 3
10:30 - 11:30 a.m.

10:30-11:30 a.m. **Panel Symposium (60 min)** **Myers Park**

Getting to the Fourth Year: Preliminary Findings Regarding the Practice of MN Beginning K-12 Science Teachers
Four presentations describing the research questions, findings, and implications of a three year qualitative/quantitative study of over 90 beginning K-12 science teachers from across Minnesota.

Panelists: *Patricia Simpson*, St. Cloud State University, *Teresea Shume*, Minnesota State University Moorhead, *Dorrie Tonnis*, University of St. Thomas

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10:30-11:30 a.m. **Panel Symposium (60 min)** **Dilworth**

Working Together: Improving Preservice Teacher Education by Collaboration
This panel consists of science educators and scientists discussing unique collaborative efforts and grant-funded projects as well as sharing research findings and suggestions for successful collaborative alliances.

Panelists: *Lena Ballone, Julia McArthur, Jodi Haney, Robert Midden, Charlene Waggoner, Kim Keller, Stephen Van Hook*, Bowling Green State University

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10:30-11:30 a.m. **Interactive Session (60 min)** **Eastover**

Giving Teachers the Credit They Deserve: Professional Development for Elementary Science Teachers
Learn about two new video teacher workshops produced by the Harvard-Smithsonian Center for Astrophysics that are intended to strengthen elementary teachers' content knowledge of force, motion and energy.

Presenter: *Nancy Finkelstein*, Harvard-Smithsonian Center for Astrophysics

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10:30-11:30 a.m. **Interactive Session (60 min)** **Elizabeth**

Arts and Sciences and Education Faculty Collaborative for Teacher Preparation
The University of Akron's Project TIMS (Teaching Inquiry in Mathematics and Science): A model of collaborative work for teacher preparation and faculty development throughout northeast Ohio

Presenters: *Katherine D. Owens and Francis S. Broadway*, University of Akron

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10:30-11:30 a.m. **Interactive Session (60 min)** **Wendover**

The New Science Literacy: Using Language Skills to Help Students Learn Science
Science offers opportunities for students to practice using language clearly and precisely. Teachers can foster the growth of language in their students and, thus teach science more effectively to achieve "enduring understanding". (The session is based upon a book written by the session presenter and soon to be released by Heinemann.)

Presenter: *Marlene Their*, Lawrence Hall of Science,University of California, Berkeley

10:30-11:30 a.m. **Contributed Paper (60 min)** **Salon C**

Implications of Diverse Meanings for 'Scientific Literacy'
Science teacher educators have a wide range of views on what 'scientific literacy' means. Inplications of this diversity are discussed.

Presenter: *Andrew C. Kemp*, University of Louisville

Who Am I? : A Preservice Elementary Teacher's Struggle with Social Identity and the Teaching of Science.
This case study investigates the influences and effects social identity has on the teaching of science in an urban elementary classroom during student teaching.

Presenter: *Paul Numedahl*, Colorado College

10:30-11:30 a.m. **Contributed Paper (60 min)** **Salon B**

Collaboration Skills as Investments in Scientific Literacy: Results of a Delphi Study
This session presents findings of a Delphi study to establish a definitive picture of the profile of an effective member of a collaborative task group.

Presenter: *Aimee L. Govett and L. Jean Henry,* University of Nevada-Las Vegas

Self-Initiated Networking: Improving the Investment in Student Teaching
This presentation discusses self-initiatated networking as a vital activity for student teachers in order to return an enhanced yield from the student teaching investment.

Presenters: *Inge R. Poole*, Vanderbilt University

10:30-11:30 a.m. **Contributed Paper (60 min)** **Salon A**

Expeditionary inquiry on the Erie Canal
This presentation will focus on relating the workshop experiences and products of a group of New York teachers as the explored the Erie Canal for two weeks aboard a 33' canal packet boat.

Presenter: *Eric A. Olson,* State University of New York-Oswego

What is Happening Here? Envivo Analysis of Preservice Images of Elementary Science Teachers at Work
This research extends the DASTT-C in better identifying images and beliefs of pre-service teachers. ENVIVO, a qualitative software program, allows a more holistic review of illustrations.

Presenters: *Julie A. Thomas*, Texas Tech University, *Jon E. Pedersen*, University of Oklahoma

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10:30-11:30 a.m. **Contributed Paper (60 min)** **Salon F**

Interdisciplinary Instruction in a Science Methods Course: Applying STS
Student reactions to engaging in an STS-oriented experience during their enrollment in a methods course a means of interdisciplinary instruction will be examined.

Presenter: *Kenneth P. King*, Northern Illinois University

Dilemmas of Teaching Inquiry in Elementary Science Methods
Teaching inquiry in an elementary science methods course creates unique dilemmas that required the instructors to examine their teaching and attempt to address these issues.

2:00-3:00 p.m. **Contributed Papers (60 min)** **Elizabeth**

Assessing the Impact of Undergraduate Mathematics and Science Instruction on Beginning Teachers' Instructional Practices

We provide a description and rationale for the development of two instruments (classroom observation and teacher interview protocols) designed to document the impact of reform-based professional development for undergraduate mathematics/science faculty and its impact on the preparation of teachers.

Presenters: *Camille L. Wainwright*, Pacific University, *Lawrence Flick*, Oregon State University, *Patricia Morrell*, University of Portland

2:00-3:00 p.m. **Contributed Papers (60 min)** **Wendover**

Determining and Meeting the Perceived Instructional Needs of the Lateral Entry Science Teacher

Data from interviews, observations, and surveys will be collected in order to create a science teaching methods course for teachers enrolled in a specific alternative licensure program.

Presenters: *Grant Holley and Jack Wheatley*, North Carolina State University

Teacher Professional Development Across States: Leveraging Resources

Faculty from two universities in bordering states are working together to provide ongoing, inquiry-oriented, science and technology professional development to teachers in rural school districts.

Presenters: *Brian, L. Gerber, Catherine B. Price, Andrew J. Brovey*, Valdosta State University, *Marianne B. Barnes and Lehman W. Barnes*, University of North Florida

2:00-3:00 p.m. **Contributed Papers (60 min)** **Salon C**

Time to Learn: The Evolution of a Successful K-12 Staff Development Model

University and K-12 educators will analyze a model that combines teacher driven science content and pedagogy learning, designed free time, collaborative curricu development, and resource support.

Presenters: *Robert E. Hollon, Robert Eierman, Karen Havholm, J. Eirk Hendrickson*, University of Wisconsin - Eau Claire, *Dawn Olson*, South Middle School

Staff Development in an Intensive Yearlong Program

In-service science teachers participating in an intensive yearlong staff development program share their perceptions of pedagogical change resulting from the experience.

Presenter: *Joneen A. Hueni*, Bellville Independent School District

2:00-3:00 p.m. **Contributed Papers (60 min)** **Salon B**

Professional Development Models: A Comparison of Duration and Effect.

Personal science teaching efficacy, outcome expectancy, and content preparation of teachers in two different professional development models (two weeks vs. 3 weekends) is explored .

Presenters: *David T. Crowther and John R. Cannon*, University of Nevada, Reno

A Professional Development Schools Model of Cognitive and Pedagogical Enhancement for Elementary Science Teachers

An investigation of the extent to which inquiry-based science learning influenced the teaching practices of pre-service and in-service teachers.

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Presenter: *Glenda Love Bell*, Texas A&M University-Commerce

2:00-3:00 p.m. **Contributed Papers (60 min)** **Salon A**

Strengthening Geology Content Courses for Prospective Elementary Teachers: Bridging the Great Divide
This study focuses on the impact of incorporating "best teaching practices" in a geology lecture and laboratory course for prospective teachers through researcher co-participation.

Presenters: *M. Jenice Goldston, Monica Clement, Jackie Spears*, Kansas State University

Big Ideas in Science: Preliminary Evaluation of Collaboratively Developed General Education Course for Elementary Education Majors
Preliminary evaluation of a course designed by a unique partnership to initiate preservice elementary teachers into the process by which scientific knowledge develops.

Presenters: *Eric A. Hagedorn, William F. Kean, Thomas A. Holme, Jane Wisniewski, Tracy J. Posnanski*, University of Wisconsin- Milwaukee

2:00-3:00 p.m. **Contributed Papers (60 min)** **Salon F**

Sociocultural Perspectives on the Teaching and Learning of Physics in Urban High Schools
This study is one that focuses on the teaching and learning of physics of five urban high school students from an African American ethnicity and backgrounds of economic distress.

Presenter: *Rowhea Elmesky*, University of Pennsylvania

Elementary Learning Communities in Science: Cooperation and Mentoring That Challenge Current Concepts of Equity
Coaching Teams, or four-person cooperative groups, were studied in a fourth and fifth grade science class. Findings include new views of equity in education.

Presenter: *Paula J. Lane*, University of North Carolina-Chapel Hill

2:00-3:00 p.m. **AETS Awards Papers (60 min)** **Salon G**

AETS Awards Presentations
Presentation of papers for Awards 4 and 5

Presiding: *J. Randy McGinnis*, University of Maryland - College Park

3:00-3:20 p.m. **Coffee Break** **Pre-Function Area**

Saturday Afternoon
Concurrent Sessions
S 5
3:20 - 4:20 p.m.

3:20-4:20 p.m. **Panel Symposium (60 min)** **Myers Park**

Interacting with Elementary Interns About Their Perceptions of Science Teaching
This interactive panel invites audience participation with preservice teachers in discussing their perceptions of science teaching.

Panelists: *G. Nathan Carnes*, University of South Carolina

3:20-4:20 p.m. Interactive Session (60 min) Dilworth

Political Action: Making a Difference in Professional Associations and Elsewhere
This session shares strategies to enhance our members' voices in AETS, the university and government. Through a case study approach, participants will practice strategies for change.

Presenters: *Barbara S. Spector*, University of South Florida, *Patricia Simpson*, St. Cloud University

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3:20-4:20 p.m. **Interactive Session (60 min)** **Eastover**

Mentoring and Constructivism: Preparing Students with Disabilities for Careers in Science
The presentation will focus on two concepts to encourage students with disabilities to participate more fully in science education and to prepare them for life situations.

Presenter: *Rita Coombs-Richardson*, University of Houston

3:20-4:20 p.m. **Demonstration (60 min)** **Elizabeth**

Summer Science Camp as a Vehicle for the Professional Development of Preservice and Inservice Teachers
Professional development pairing preservice (elementary and secondary) and inservice teachers for three weeks provides grade 4-8 students with a standards-based summer science experience.

Presenters: *Laura Henriques and William C. Ritz*, California State University-Long Beach

Enhancing Prospective Science Teachers' Knowledge of the Importance of Scientific Modeling Using MODEL-IT
Models are important tools used by scientists. Use of modeling software to enhance prospective science teachers' understanding of the importance of models will be examined.

Presenters: *Michael J. Cullin and Barbara A. Crawford*, Pennsylvania State University

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3:20-4:20 p.m. **Contributed Papers (60 min)** **Wendover**

Learning Cycle Lesson Plan Rubric
Analysis of "Science Learning Cycle Lesson Plan Rubric" indicated the instrument is effective for evaluation of lesson plans and predicting subsequent success in classroom implementation.

Presenters: *Cheryl White Sundberg, Lea Accologouonm, Dennis Sunal, Cynthia Sunal, Judy Giesen*, University of

Alabama, *Kathy Cabe Trundle*, Ohio State University

Science Drawings as a Tool for Analyzing Conceptual Understanding
Preservice elementary teachers' drawings of scientific phenomena were analyzed with respect to what they indicated about teachers' understandings and beliefs. Through drawing, teachers were able to reflect on their own beliefs, the limits of their understanding, and how drawings might be used as an assessment tool in the classroom.

Presenters: Mary T. Stein and Shannan McNair, Oakland University

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3:20-4:20 p.m. Contributed Papers (60 min) Salon C

Supporting Beginning Science Teachers: What Can and Cannot be Expected From Induction Programs
Induction programs are not a panacea for improving the performance for science teachers. The are programs that make specific contributions to the professional development of a teacher. In this paper, we discuss what contributions can and cannot be expected.

Presenters: *Julie A. Luft and Nancy Patterson*, University of Arizona, *Teresa Potte*r, Rio Rico High School**A Gap Too Wide : Expectations vs Reality: The Case of a Preservice Science Teacher**
This case study describes the science teaching and learning beliefs and classroom practices of a preservice chemistry teacher who decided to resign from student teaching.

Presenter: *Kathleen M. Lesniak*, State University of New York at Buffalo

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3:20-4:20 p.m. Contributed Papers (60 min) Salon B

If Inquiry is so Great, Why isn't Everyone Doing It?
This paper chronicles fifty prospective elementary teachers who reflect on the meaning of scientific inquiry before, during, and after their field placement experiences.

Presenter: *Rebecca Reiff*, Indiana University

Inquiry and Effective Science Instruction at the Middle Grades Level. A Collaboration between the College of Education at UNC Charlotte and Gaston County Schools
The session is provides an overview of a project designed to implement the use of a Standards-based approach to instruction (Inquiry) into middle grades science classes in Gaston County (NC) Schools.

Presenter: *Warren J. DiBiase*, University of North Carolina-Charlotte, *Eugene P. Wagner*, University of Pittsburgh, *Suzanne Riley*, Gaston County Schools

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3:20-4:20 p.m. Contributed Papers (60 min) Salon A

Teaching Conceptually: The I-A-A Model
Lessons learned from teaching fundamental exological concepts in concrete ways provide an alternative, dynamic model for teaching conceptually in the classdroom as well as outdoors.

Presenters: *Bruce Johnson*, University of Arizona, *Mike Mayer*, University of Arizona & Tuscon Unified School District

Shifting Teachers' Thinking: Classroom Research in Integrating Science and Technology Design
This paper addresses the effects of requiring action research projects in the science education of elementary school teachers participating in a professional development graduate program in education.

Presenter: *Janice Koch*, Hofstra University

3:20-4:20 p.m. **Contributed Papers (60 min)** **Salon F**

What's New (if anything) in Cooperative Learning for Science Instruction?
What have we learned about cooperative learning over the past twenty years? This session will present ideas about how we should use cooperative learning today.

Presenter: *Scott B. Watson*, East Carolina University

3:20-4:20 p.m. **Contributed Papers (60 min)** **Salon G**

Helping Middle School Science Students Relate to New Concepts Through Physical Modeling: A Bodily-Kinesthetic Approach
Presentation of a teacher,s self-reflective research into using physical modeling, a bodily-kinesthetic instructional technique, in middle school science education.

Presenter: *Deborah S. D. Burke*, Joseph Middle School

Structure and Agency in Science Class: The Story of a Student Emergent Curricu
We examine the extent to which a student-emergent science curricu allowed students to resist their disempowered position and participate in science in less reproductive ways.

Presenter: *Gale Seiler*, University of Pennsylvania

Saturday Afternoon
Concurrent Sessions
S 6
4:30 - 5:30 p.m.

4:30-5:30 p.m. **Interactive Session (60 min)** **Dilworth**

Using Moral and Ethical Issues in Science Teacher Education
This session will present a paper and offer an interactive format for participants to consider the use of socioscientific issues in science teacher education.

Presenters: *Dana L. Zeidler and Troy D. Sadler*, University of South Florida

4:30-5:30 p.m. **Interactive Session (60 min)** **Eastover**

Effective Integration of Standards-Based Curricu Materials into Science Methods Classes
This session will illustrate an effective strategy for using curricu materials to challenge preservice students' ideas about inquiry, content, and teaching.

Presenters: *Janet Carson Powell and Sharmila Basu*, BSCS

4:30-5:30 p.m. **Contributed Papers (60 min)** **Elizabeth**

Sisters in Sport Science: A Sport-Oriented Science and Mathematics Enrichment Program
Sisters in Sport Science is a comprehensive and gender-sensitive educational program, which uses sport as a vehicle for teaching girls science and mathematics.

Presenters: *Penny L. Hammrich, Tina Sloan Green, Beverly Livingston*, Temple University, *Greer Richardson*, LaSalle University

The Solar Decathlon: Enhancing Student Achievement and Motivation through Intercollegiate Competition
The Solar Decathlon is an intercollegiate program for students to design, build, and operate solar powered homes. The competition rates the aesthetics and efficiency of these student-designed homes.

Presenter: *Melissa DiGennaro King*, George Mason University

4:30-5:30 p.m. **Contributed Papers (60 min)** **Wendover**

UTeach: Secondary Science & Mathematics Teacher Preparation Program
The presentation will describe an innovative secondary science and mathematics teacher preparation program at The University of Texas at Austin. The UTeach program is a collaborative effort of the College of Education and the College of Natural Sciences and the Austin Independent School District to recruit, prepare, and support the next generation of science and math teachers for the state of Texas. The program integrates practical experience and scholarly investigation, with early and on-going field experiences that capture the imagination of preservice teachers and provide an foundation for their more advanced pedagogical courses.

Presenter: *James P. Barufaldi*, University of Texas

The Self-Related Understandings of Participants in an Advanced Degree Program in Science Education
This research uses document analysis and interviews to understand changes in the notion of "self" as expressed by teachers participating in a long-term, distance graduate program.

Presenters: *Elizabeth Hancock and Alejandro Gallard*, Florida State University

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4:30-5:30 p.m. **Contributed Papers (60 min)** **Salon C**

Building Confidence in Preservice Elementary Science Teachers: Two Professors Tackling the Same Problem
Teaching confidence is examined in preservice elementary teachers in relationship to the development of science conceptual understanding, understanding of constructivism, and reflective practice.

Presenters: *Robert Bleicher and Joan Lindgren*, Florida Atlantic University

Caring: A Characteristic of Expert Science Teaching
This paper contributes to the body of knowledge on the ethic of caring using the perspective of seven identified proficient-to-expert science teachers.

Presenters: *Meta Van Sickle*, College and University of Charleston, *Gary Varella*, George Mason University

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4:30-5:30 p.m. **Contributed Papers (60 min)** **Salon B**

Middle School Science Teachers' Beliefs and Values Regarding the use of Probeware to Teach Science Content
Findings of this study determined what factors influenced conceptual change in middle school science teachers' pedagogical views and beliefs regarding the integration of probeware technology.

Presenter: *David R. Wetzel*, Bloomsberg University of Pennsylvania

Science Teacher Education in Electronic Technologies: Addressing our "Failure to Connect" in Many Senses
Science teacher education in the use of electronic technology often "fails to connect" (in Jane Healy's phrase) in many different senses. Let's discuss approaches to the problem.

Presenter: *David Jackson*, University of Georgia

4:30-5:30 p.m. Contributed Papers (60 min) Salon F

Teaching Interactive Science Lessons in a High School's Remediation Program: What Can We Learn In Helping Students Pass a High Stakes Examination?
Preservice action researchers used interactive and hands-on approaches to teach science objectives from a high stakes graduation exam to high school remedial science students.

Presenters: *Charles J. Eick, Jeannine Ott Eubanks, Ashley Belcher, Rachel Aldridge*, Auburn University

Using Environmental Assessments to Improve Teaching and Learning in High School Biology
This reseach project involved using a learning environment assessment with students to determine which factors in the learning environment led to better scores on state administered tests, and better attitudes toward science.

Presenter: *Cindy Hoffner Moss*, Charlotte Mecklenburg Schools

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4:30-5:30 p.m. Contributed Papers (60 min) Salon G

Problematizing a General Chemistry Classroom: Understanding Student Learning Orientation and Triarchic Personal Motivation
This paper reports a study of students' beliefs and learning orientations to suggest possible explanations for surface and deep learning during high school chemistry activities.

Presenter: *M. Randall Spaid*, Florida State University

Chemistry Students, Challenges in Using MBL's in Science Laboratories
This case study examines students challenges in using MBLs as a learning tool in high school chemistry classes.

Presenter: H*akan Y. Ytar*, Florida State University

4:30-5:30 p.m. Planning Meeting (60 min) Myers Park

AETS 2003 Planning Meeting
All AETS members are invited to attend this planning meeting for the 2002 AETS conference to be held in St. Louis

Patricia Simmons, Chair, AETS 2003 International Conference Committee

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7:30-9:30 p.m. WISE Dessert Function Salon D

All AETS members are invited to attend this Women in Science Education get-together. (Tickets must be purchased prior to this event.)

Sunday Morning
8:00 am - 12:00 p.m.

AETS Board Meeting	**Salon A & B**

2002 AETS Conference Papers and Presentation Summaries

TEACHING SCIENCE METHODS COURSES WITH WEB-ENHANCED ACTIVITIES

Alec M. Bodzin, Lehigh University

Theoretical Background: Learning Science with the World Wide Web

Learning science in today's classroom does not have to be restricted to text-based curricular resources. Websites present learners with a wide range of science activities in various formats ranging from text-only information to providing authentic real-time data sets and interactive simulations. Owston (1997) contended that the World Wide Web is likely to bring new learning resources and opportunities into the classroom, provide teachers and students access to more resources, and promote improved learning. Many Web-based curricular resources have been developed for use in K-12 science classrooms. Some of these resources have been described in the literature (Alloway et al., 1996; Beaujardiere et al., 1997; Berenfeld, 1994; Bodzin, 1997; Bodzin, 2001; Bodzin & Mamlok, 2000; Bodzin & Park, 1999; Cohen, 1997; Coulter & Walters, 1997; Feldman, Konold, & Coulter, 2000; Friedman, Baron, and Addison, 1996; Gordin et al., 1996; Songer, 1996; Songer, 1998; Wallace & Kupperman, 1997).

The Web can encourage students to learn independently of a teacher. Materials can provide prompts for students to examine evidence (data), compare different viewpoints on issues, and analyze and synthesize existing data sets to formulate conclusions. The Web also allows for the use of various instructional resource types to enhance student science learning. These resources include:

- Scientific visualizations - These are rich representations that present scientific relationships as visual patterns and provide data-intensive descriptions of phenomena.
- Simulations - Interactivities used to simulate and explore complex phenomena.

- Virtual Reality - This technology enables a user to interact with and explore a spatial environment through a computer.
- Animations or Video clips - Animations or video clips to illustrate science content, concepts, or processes.
- Still images - Still images to illustrate science content, concepts, or processes.
- Spreadsheets - Spreadsheets can be used in the instruction.
- Distributed information sources - Information sources are distributed among many sources including real-time data, peers, mentors in many locations.

The Web offers many advantages over traditional text-based instruction for individuals to learn science. These include:

1. Information is current - Many different kinds of science information can be found. New scientific discoveries are made each day and the Web provides learners with access to updated knowledge.

2. Access to data - Learners can access large amounts of current and archived scientific data. Data exists from scientists' labs as well as from scientific tools in the field such as drifter buoys in the ocean or seismic sensors placed in the earth. Learners can retrieve data from remote geographical distances. Web-based data is different than data that is presented in curricular text materials. Data can take the form of a digital image or a 360 degree panorama that can be explored.

3. Access to scientific experts - Learners can use the Web to ask questions of scientific experts. The Web enables authentic student collaboration with scientists using Web-based discussions and group tasks.

4. Motivation - Materials may be presented to learners in a motivating form. Examples include the use of video and interactive simulations to engage learners in a task.

5. Communication - The Web can provide students with an authentic audience with which to communicate.

6. Remote explorations - The Web provides a way for students to explore remote geographic locations that they would otherwise not be able to view.

The Web can provide supports for learning processes that are infused with constructivist principles. Constructivist conceptions of teaching and learning assign primary importance to the way in which learners attempt to make sense of what they are learning (Krajcik et al., 1994). In a Web-based environment, learning can be an active process where learners explore ideas, compare and synthesize resources, and revise ideas. The Web may provide a context for authentic learning by presenting learners with authentic real world tasks that require problem solving and reasoning to achieve a collaborative goal (Bodzin, Cates, & Vollmer, 2001). Web-based conferencing and the sharing of student-created work can provide learners the opportunity to articulate their reasoning as they solve problems. Web-based activities can provide task structuring that requires learners to think about their own learning as they solve problems and seek out alternative explanations. Collaborative Web-based learning involves social interaction and a sharing of collective knowledge in which the peer dialogue involves learners in the social construction of knowledge.

Relevance to Science Teacher Education

Recent science and technology education reform initiatives (American Association for the Advancement of Science, 1993; ISTE, 2000; NRC, 1996) emphasize incorporating instructional technologies into classroom science curricular contexts and provide guidelines for the preparation of science teachers. The World Wide Web is changing the way science education content is being delivered in K-12 classrooms. The Web is accessible worldwide, relatively easy to update (compared to traditional delivery systems such as textbooks and CD-ROMs), and adds new capabilities almost daily. Teachers and students in science education classrooms today can access many Websites that purport to provide "science education." Websites present learners with a wide range of science content in various formats ranging from text-only to authentic real-time data sets and interactive simulations. With the simplification of Web-publishing software, one no longer needs to have strong technical skills to publish a Website. Almost anyone--K-12 students, science educators, scientists, members of special interest groups, and for-profit commercial enterprises--can become a content provider for a science education site.

A variety of instructional practices can be used to integrate the Web in elementary and secondary science methods courses. The Technology-Based Teacher Education program at Lehigh University has designed and developed Web-based interactivities and instructional systems to support learning science. These materials have been an intricate part of the science education methods courses during the past two years. These Web-based interactivities are used to model how visual instructional technologies can be used to address students' naïve conceptions of science, how science teachers can help students perceive knowledge as constructed, provide students with an effective model to develop critical thinking skills, and meet standards for inquiry-based teaching and learning.

Web-Enhanced Activities

This demonstration session illustrated how Web-enhanced activities are used in the elementary and secondary science methods courses at Lehigh University. The Web-enhanced activities and related course resources are available online at:

- Science Education at Lehigh University: http://www.lehigh.edu/~amb4
- Science Education Courses at Lehigh University: http://www.lehigh.edu/~amb4/courses
- Web-based Inquiry for Learning Science manual and instrument:

http://www.lehigh.edu/~amb4/wbi/

Specific examples that were highlighted in the session included using data collection activities located on the LEO EnviroSci Inquiry Website, Science-Technology-Society role playing simulations, activities that allows students to develop skills in understanding location by exploring a variety of unique geological formations using QuickTime Virtual Reality (QTVR) panoramas and topographic maps, and virtual photojournals to explore watershed features and societal issues. The use of the Web-based Inquiry for Learning Science (WBI) manual and instrument in the science methods courses was also described. Below is a more detailed description of the activities in the LEO EnviroSci Inquiry Website.

LEO EnviroSci Inquiry

LEO EnviroSci Inquiry (http://www.leo.lehigh.edu/envirosci/) is indexed into five interconnected areas: Lehigh River Watershed Explorations, Environmental Issues, Geology, Weather, and Data Collection Activities. Curricular activities actively engage learners in data collection, analyzing data, working with Web-based Global Information Systems (GIS) databases, and learning in interdisciplinary contexts. The Website enables classroom teachers to implement science teaching strategies that incorporate Web-based and other technologies into the classroom. Curricular activities emphasize student-directed scientific discovery of their local environment.

Lehigh River Watershed Explorations

The main goal of Lehigh River Watershed Explorations area (http://www.leo.lehigh.edu/envirosci/watershed/curricular/) is to present science to K-12 learners in a historical perspective by engaging them in a detailed study of the Lehigh River watershed. This watershed has a very rich history that presents learners with a unique opportunity to observe how the American industrial revolution has impacted a watershed over time. Stories are presented in the *History of the Lehigh Watershed* section that enable learners to explore science from a historical perspective and to observe how science and technology may impact society over time.

The *Lehigh River Watershed Photojournal* provides learners with the opportunity to virtually explore the Lehigh River watershed. The photojournal contains MPEG movie watershed flybys that provide the learner with a graphical overview of the topography of the area. GPS (Global Positioning) coordinates index the photojournal. In addition to digital images of the area, the photojournal Web pages contain short MPEG video clips and QuickTime Virtual Reality panoramas that allow learners to zoom in on specific physical features.

The *Water Quality* section contains background information and protocols that assist learners using Vernier CBL (Calculator-Based Laboratory) units and graphing calculators to collect water quality data. Data reporting forms are provided on the Website that enable learners to submit collected data to the LEO water quality database. This data can then be compared to other water quality data located on the Website. Web-based data links to the Lehigh River's

USGS (US Geologic Survey) monitoring stations provide river flow data and real-time discharge data.

The *GIS* (Geographical Information Systems) section contains a variety of interactive maps of the Lehigh watershed. GIS mapping provides a spatial framework for analyzing environmental data such as water quality data and relating it to the characteristics of the land around it. Unlike static maps (such as the road maps you get at the gas station), GIS not only lets you view a map, but also lets you query the map for information that is not displayed. Figure 1 is an example of a land use map from the watershed.

The *River Explorations* and *Curricular Activities* sections provide innovative inquiry-based water quality and watershed studies activities developed by our research group and partner organizations.

Environmental Issues

The Environmental Issues area (http://www.leo.lehigh.edu/envirosci/enviroissue/) contains links to Science-Technology-Society (STS) issues-based approach simulations developed by our research group and partner organizations. These simulations provide learners with the experience of learning science and technology in the context of human experience involving real-life controversial issues. Engaging in an authentic issues makes environmental science instruction current and part of the real world. In these simulations, learners investigate a real-world controversial issue from different perspectives. After they complete their investigation, a public forum or debate is conducted to determine the next course of action on the issue. Classroom debates on STS issues offer learners a forum to think critically about the role that science plays in societal issues. These simulations acknowledge the connection between science and the decisions individuals make about social issues.

Weather

The Weather area (http://www.leo.lehigh.edu/envirosci/weather/) contains two distinct curricular resources for learners to explore weather phenomena. The first resource, *Phenomenal Weather Explorations,* is a series of guided Web-based Explorations of unique weather phenomena designed for learners in grades 4-8. In these explorations, students learn the science of hurricanes, tornadoes, lightning, and the Green House effect. The second resource, *Bits of Biomes,* provides a learning environment that uses a guided inquiry-based approach for learners to investigate characteristics of biomes including climatic differences, populations, and ecosystems in terrestrial biomes. In *Bits of Biomes*, learners investigate the driving question: "Do selected cities in our study really exhibit the characteristic climatic conditions of their defined biome?" Learners work in groups to collect climatic data on selected cities that characterize different biomes. They use spreadsheets to explore patterns in their climatic data. Climatic data in different biomes are compared. The groups research characteristics of a particular biome that includes people and culture, animal life (vertebrates and invertebrates), plant life, and economic conditions. Each group contributes a section to a class "World Travel Book." The "World Travel Book" can be a class Website, a hypermedia artifact, or a traditional paper artifact. Throughout the implementation of the unit, students participate in hands-on experiments that focus their learning on topics that include habitats, predator/prey relationships, adaptations to environments, and food chains.

Geology

The Geology area (http://www.leo.lehigh.edu/envirosci/geology/) contains interactivities for learners to use virtual reality in their science investigations. "Which Way Is North?" is an activity that allows learners to develop skills in understanding location by exploring a variety of unique geological formations using QuickTime Virtual Reality (QTVR) panoramas and topographic maps (Figure 2). "Dino Inquiry" allows learners to explore a variety of dinosaur fossil bones from the Dinosaur National Monument quarry using panoramas and digital still imagery. "Geologic Explorations" allows one to explore a variety of unique geological formations through the use of QTVR.

Data Collection Activities

The Data Collection Activities area (http://www.leo.lehigh.edu/envirosci/data/) connects learners to a variety of earth and environmental science data sets and collection activities currently underway at LEO (Lehigh Earth Observatory). The *LEO WeatherNet* is an electronic network of weather and water monitoring stations. Learners can access real-time and archived weather data from weather and water monitoring stations near the Lehigh University Campus and from lake monitoring stations on the Pocono Plateau. The *LEO hydroprobe* area contains a database of water quality data taken from a hydroprobe located on the lower reaches of the Lehigh River. The probe measures a variety of water quality parameters and is logged on an hourly basis. Classroom learners use this data to examine temporal patterns of the health of the river. *The LEO Seismic Station* area contains data from a broadband seismic station located on South Mountain at Lehigh University. Data collected from the seismic station provides information on active seismicity in northeastern Pennsylvania. This station is a part of the Northeastern Regional Seismic Network, which monitors earthquake activity in the eastern U.S. In addition to learning about earthquakes, learners can link to the GSN (Global Seismic Network) maintained and operated jointly by IRIS (Incorporated Research Institutes in Seismology) and the US Geological Survey. *The Salamander Response to Climate Change project (SRCC)* focuses on the use of salamanders as a natural indicator of changes in environmental conditions. Learners can access current research being conducted in Northeast Pennsylvania at South Mountain, Hawk Mountain, and the Lacawac Sanctuary to examine salamander activity in relation to environmental conditions. Environmental data, recorded on data loggers in the field, can be compared with salamander activity levels to predict salamander response to climate change.

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HOW IS YOUR LAWNMOWER WORKING? UNDERSTANDING SCIENTIFIC INQUIRY THROUGH METAPHORS

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Metaphors are used as a typical way to negotiate and to describe our everyday experience. In particular, metaphors provide an effective means to help visualize abstract ideas (Davidson, 1976; Miller, 1979). Lakoff & Johnson (1980) indicate that metaphors are a key mechanism for learning in all disciplines, including science. Teachers commonly employ metaphors to engage students and to make abstract ideas appear more concrete. In this way, metaphors are a component of the scaffolding teachers employ to aid in students' construction of new understanding.

Academic research scientists also use metaphors to make the abstract more concrete. In response to interview questions addressing what their conception of scientific inquiry was, many scientists used metaphors. Scientists' metaphors about science serve to elucidate the expectations scientists have regarding the nature of science and the process of doing scientific inquiry. Ganguly (1995) noted that in order to make the abstract more concrete, "scientists have often resorted to metaphors to build up their thought processes." Similarly, Tobin and Tippins (1996) found that metaphors help understand a new experience by forming creative links between the known and the unknown.

Understanding Metaphors

We define metaphor using a four-item framework (Pugh, Hicks, Davis, & Venstra, 1992) of: *grounding*, *form*, *correspondence*, and *connotation*. In their model, Pugh, et al. build on Lakoff & Johnson's (1980) model and describe grounding as the need for a metaphor to be based in a shared experience. Form relates to the commonality of imagery between the two concepts. For example, in comparing the structure of the atom to the solar system, the form is an image of objects orbiting around a center. Correspondences are the multiple points of comparison between the two concepts within the form. The more correspondences, the more successful is the metaphor. Finally, connotation addresses the extent to which a metaphor defines a particular experience. That is, how much has the metaphor entered the culture?

Methodology

Interviews with 52 science faculty members at a large midwestern academic research institution were conducted using a semi-structured interview protocol designed to probe the subject's conceptions of scientific inquiry (Harwood, Reiff, & Phillipson, accepted). A blended grounded theory approach was employed. A purposive sample was utilized and data was collected, analyzed, and coded in a systematic way. Emergent categories were verified and tested through additional analysis. Patterns and connections between categories were revealed and further analysis was conducted to verify that these were grounded in the data. Interviews were tape-recorded and interviewers took field notes during the interview. Together, the transcripts and field notes represent our data. The scientists interviewed were disbursed across nine science departments (anthropology, biology, chemistry, geography, geology, medical sciences, physics, applied health, and environmental affairs).

After conducting the interviews, we independently analyzed the science faculty members' responses to each of the eight interview questions. Potential metaphors were identified. We compared our independent lists of metaphors and agreed on a consistent understanding regarding how to classify items. The result was a list of metaphors and another list of every day examples. We then independently read through the interviews a second time to double-check for a complete list of metaphors and to collect the metaphors into initial categories. When a discrepancy between our individual categorizations occurred, the results were discussed until a mutual agreement could be made (Tobin, 2000).

Metaphor and Analogy

The first key decision was to articulate for ourselves the difference between a metaphor to be used in this research and an analogy. Analogies differ only by a slight degree from metaphors (Duit, 1991). Duit provides the following distinction between metaphors and analogies:

> An analogy *explicitly* compares the structures of two domains; it indicates identity of parts and structures. A metaphor compares *implicitly*, highlighting features or relational qualities that do not coincide in two domains.

This distinction served as a guide for us. We identified a number of instances when scientists made explicit references to familiar items, but did not have the imaginative quality required of a metaphor. Using Pugh's definition of metaphor (1992), an analogy often is grounded in common experience and has a form that relates two concepts. Unlike a metaphor, however, there is no imaginative structure within the analogy. That is, there are no correspondences that give a metaphor its shape and power. Analogies may, however, have a connotation or context within the culture.

Metaphor and Every Day Life

Two categories that emerged from the data were the metaphor category and the every day life category. It was important that we defined the boundaries of these categories clearly to keep confusion at a minimum.

Quotes that were used to illustrate the process of scientific inquiry were classified under the metaphor category. For example, a chemist provided the following quote in which he used the metaphor of a foreign language to illustrate the importance of having a large knowledge base of facts to draw from in order to make meaningful connections.

> …this ability to think abstractly about a problem is absolutely crucial. It's also crucial to have a lot of facts at your disposal…it's very vaguely like learning a foreign language. You have to learn syntax and grammar and that's the thinking abstractly part, how things were generally put together. But, also to learn a foreign language you have to learn vocabulary. In science you must know a set of a reasonably large number of facts.

Scientists sometimes used examples of how inquiry could be used in every day life situations. As an example of how inquiry plays a role in a person's every day business, a medical science researcher gave the following response. These every day experience were not classified as metaphors.

> …teaching, interviewing, fixing a car, cooking, business. Let me put it this way, I can't think of many things that scientific inquiry doesn't, one way or the other, play a role in a person's life. They are doing it but they don't know it's scientific inquiry. They just ask the question, search for an answer, and then make improvements next time. That is essentially what is happening in their thinking.

Results and Discussion

Eighteen of the 52 scientists interviewed used metaphors to elucidate aspects of the process of scientific inquiry. At least one scientist from each department except environmental affairs used at least one metaphor in their descriptions of scientific inquiry. We have no explanation for the lack of environmental scientists or for the low percentage of physicists (20%) and medical scientists (20%) who did not use metaphors to enhance descriptions of scientific inquiry. All other departments had between 33% and 60% of scientists use metaphors when referring to scientific inquiry.

The department with the highest percentage of metaphor use (60%) was the geology department. Metaphors in the geology department related to "building blocks" or the use of rocks to convey processes in scientific inquiry. This contrasts with other scientists, who tended not to use metaphors that spring from their own disciplines. In this, perhaps, geologists have an advantage over other disciplines such as molecular biology. Using rocks in the form of the metaphor does provide a connotation that may not be available to other disciplines.

We found that the scientists we interviewed used metaphors to articulate aspects of their conception of scientific inquiry. The metaphors provided powerful images to complement descriptions of important aspects of scientific inquiry. Scientists used metaphors to describe the process of connecting data, the importance of knowing how and when to use resources or tools, the ability to stay focused on the process of an investigation, the relationship between problem solving and scientific inquiry, and the necessity of enhancing scientific knowledge by adding creativity and individuality to an investigation.

Often the metaphor used by a scientist filled multiple purposes and contained a rich set of correspondences. They accomplished this by using metaphors grounded in everyday experiences as the form within which to develop correspondences between a common or public understanding of science and their own private understanding of the practice of scientists.

By describing scientific inquiry in metaphorical terms, these scientists presented an understanding of how science is actually conducted that is not always evident in science textbooks or in science classrooms. Ganguly makes a distinction between public and private science that illustrates the lack of communication between how science is portrayed in the classroom (public science) and the science that scientists practice (private science). Holton (1973) explains that in the classroom, "factors such as emotional, aesthetic and social forces intrinsic to scientific inquiry need to be referred to when delivering science lessons." Science is too often presented as a dry and passionless endeavor. This hides from public view the struggles and the imaginative process of science that reflects the way in which science is actually practiced.

Misrepresenting how science is conducted can result in students developing conceptions of science that are inconsistent with the actual practices of scientists. Students may think science is dry, boring, and unimaginative based on experiences with textbooks and/or with science classrooms (Moravcsik, 1981). Below we show scientists who use metaphor as a powerful medium for describing the more iterative and engaged scientific process—a process with an emotional commitment.

The Metaphors

Making Connections

In the interviews of 52 scientists, the ability to "make connections" between the data was most frequently cited as the most important characteristic of doing scientific inquiry (Harwood, et. al.). This skill in making connections involves analytical and critical thinking skills in order to see patterns and inconsistencies across the data. Scientists recognized the importance of individual pieces of data but also how the data can be used to construct a larger picture.

A geologist uses the metaphor of "building bricks" to represent the significance of each piece of data in the analysis of the larger set of data.

> I think science has a very big building of bricks, not always a capstone. Everybody puts their brick here and there and not all bricks are superior important ones like a capstone or something but every brick counts.

Even data from separate investigations can be connected to enhance an understanding of a scientific concept.

Another part of making connections to be able to focus on current investigations, but also to have insights into implications of the study and further possibilities for research. A biologist compared this process to a chess game in that one needs to be able to "recognize the important questions but be able to look ahead 5-6 moves."

A chemist used the metaphor of learning a foreign language to describe the process of connecting data and making sense of it. The words of a language do not make sense without the context of sentences to give meaning to the words. This is similar to the data of an investigation. In order for the data to make sense, the data must be connected to larger concepts and ideas of the investigation. This gives the data meaning.

Geologists, naturally, tended to use the metaphor of rocks to bring meaning to concepts. In one case, rocks were used in the image of creating a mosaic art piece. The artist had to decide how the rocks would be placed and arranged on the picture. The important part is not to loose track of the individual rocks. At first the artist might just have a pile of yellow, purple, and brown rocks but how the rocks are placed together or connected will determine how the picture will look.

The metaphor of scientific inquiry as building a mosaic artwork is related to the more general metaphor of being able to "see the big picture." Scientists valued the ability to see the big picture as well as to focus on the details of an investigation. A geographer used the metaphor of being able to see the forest through the trees as an essential characteristic of an investigator in scientific inquiry. Scientists who are so focused on the details of an investigation (the trees) may not be able to take a step back and see how the data are connected (the forest).

> Being able to synthesize the big picture but also at the same time concentrate on the details- not losing sight of the forest from the trees, but also looking at the tree itself.

This ability to make connections is an essential characteristic of conducting scientific inquiry investigations. This skill requires the ability to synthesize large amounts of data and to see the patterns that exist between the data so that the meaning can be given.

Utilizing Resources

Scientific inquiry investigations involve the use of resources or tools that will help bring a study to a fruitful resolution of the investigator's question (Harwood, et. al.). How a scientist uses the available resources, then, impacts the results of the study. Thus, scientists need to be skilled in selection of the appropriate tool for the investigation and must be able to use the tool in a proficient manner.

A geographer stressed knowing how to use the tools in inquiry investigations using the metaphor of teaching someone to fish. If someone wants to feed him/herself, one does not just give that person the fish. To teach a person how to fish, you give them a rod or the tools necessary to fish then assist them in developing skills and techniques in fishing. This is similar to carrying out scientific inquiry investigations—the investigator must know how to conduct the research and not just be focused on getting the fish or the "right answer."

Several scientists mentioned the role of a tool bag in an inquiry investigation. Each tool bag contains methods, instruments, questions, techniques, and it is up to the scientist to decide which tool to use, and when, in an investigation.

> …and then I think the other thing that you need is a kind of tool bag…and you gotta have a lot of different tools…because typically one tool isn't going to get you what you wanted.

Knowing how to make effective use of resources equips scientists to conduct successful investigations. A chemist compared competency with the tools used in inquiry investigations with the skills used in painting. A painter must know how to use the brush, the paints, and the canvass to construct a painting, just as a scientist must be proficient at using available tools to enhance investigations.

Focusing on the Process

An important feature of inquiry investigations is staying focused on the process of an investigation. Scientists who are primarily concerned with proving a hypothesis may overlook data in the rush to communicate findings to peers. An anthropologist described, "Inquiry is what keeps you from jumping to conclusions." The process of conducting an inquiry investigation involves stages such as forming questions, reviewing the literature, articulating an expectation, designing and conducting the study, interpreting and reflecting on the results, and communicating the findings. By following these stages with the opportunity to repeat previous stages better ensures that investigations are thorough and contain higher levels of internal validity.

Staying focused on the process of an investigation also means that the investigator can be more open to discoveries or to data that is contradictory to what was expected. Being open-minded or flexible in an investigation is an important characteristic of an investigator (Harwood, et al.). As a physicist explains,

> It's like an artist. An artist does not know the answer. An artist in the process of creating something lets the process lead them to whatever they are doing. They experiment and that's kind of what you do in science.

> Scientific investigations do not progress in a linear way where one step invariably leads to the next. Scientists may not know which stage will come next in an investigation and so, must be open to the process in the same way an artist is open to their muse.

Problem-solving

Some scientists related scientific inquiry to solving problems in their everyday lives. People can approach and solve problems in ways similar to the way scientists solve scientific problems. Some scientists compared the process of scientific inquiry to farming or gardening.

> Farmers do that today in determination of when to plant, what to utilize in the fields. They use the available evidence of what they're told and they fit that in with their experience and what their father or their grandfather did…

If further studies are needed, the farmer or gardener may repeat any of the stages mentioned earlier and redesign the experiment using different controls.

> Let's say somebody is a gardener. Maybe they tried growing tomatoes in different locations or different amounts of sun or the soggy part of the garden as opposed to the dry part of the garden.

The farmer can then decide to communicate the findings to his peers (farmers) or to the community. Scientific inquiry results in enhancing understanding of problems and in coming up with solutions to these problems.

A common metaphor for problem solving strategies is one we call "the lawnmower metaphor." The Lawnmower metaphor refers to a set of metaphors that take the form of repairing a complex machine. The metaphor is used to describe the systematic process that scientists use as part of the problem solving strategy within an inquiry. This metaphor also contains within it the need of scientists to use failure to inform the progress of their inquiry. For instance, one might fill the engine with gas. If the problem continues, they may try changing the filter. If changing the filter does not solve the problem, they then may change the oil, and so forth. This process also moves from simple solutions to more complicated solutions – another commonly identified characteristic of the nature of science.

The Lawnmower metaphor and related forms also can be used to demonstrate that science is not deterministic. That is, the notion that the result of an experiment is not strictly "right" or "wrong". This is a common student conception of science that arises from their experience in the classroom or in a school laboratory (Ganguly, 1995). On the contrary, practicing scientists use the results of experiments for guiding their overall inquiry.

Putting yourself in your work

Conducting science does not involve following a list of procedures that results in an answer. Scientists described doing science as a much more creative endeavor where they design methods and look at data in many different ways. Thus, to contribute beyond what is already known entails putting a little of yourself into your work. Otherwise, you are just doing what someone else has done and are not adding to the scientific knowledge base.

A medical scientist compared coming up with something new in science to cooking. Just following a recipe as in cooking does not lead to a new concoction. Adding a spice here and there or adding more to the recipe can create a recipe unlike the original. Scientific progress can result from trying out different variations.

Scientific inquiry is also an active process where stages are repeated, data analyzed, and communicated with others. An anthropologist compared doing scientific inquiry to playing a cello.

> Yo, Yo Ma, who is a cello player, says that interpretation is not passive. It's not just playing the notes as they are written; it's putting something of your own, yourself there.

Scientific inquiry was also compared to the act of writing poetry. The construction and selection of styles of poems is similar to the process of designing and choosing methods to form and shape a study. Writing poetry and designing a study are creative endeavors that involve the self in producing a unique creative work within a structural frame.

Thus, teaching students to memorize steps to follow in an investigation or to constantly verify results of others leaves little room for the creative side of science. The alternative is to have students continue to think that science is an unemotional, detached, and uninvolved activity where results are known and nothing out of the ordinary ever happens. A scientist from applied health described the importance of involving yourself in your work and not in merely reciting facts found in a science textbook or in scientific journals or books.

> That was a big realization for me—you don't actually just learn the book and spit it back; it's like you are making the book.

Conclusion

> When it comes to atoms, language can only be used as in poetry. The poet, too, is not so concerned with describing facts as with creating images' (Niels Bohr, quoted in Mashhadi, 1997).

The metaphors commonly used by scientists to articulate aspects of their conception of scientific inquiry fell into five categories: making connections, utilizing resources, focusing on the process, problem solving, and putting yourself in your work. Specific metaphors such as lawnmower repair, painting, musical performance, cooking, and the tool bag elucidate the process of scientific inquiry and the characteristics of good science.

These metaphors help us to understand that the community of scientists values certain conceptual approaches and experiences. Knowing this, teachers of science can choose activities that reinforce these perspectives and develop the skills most valued by active research scientists. The use of metaphors helps to describe scientific inquiry in such a way that relates scientific practices with experiences which people are familiar. Students can begin to see themselves in their everyday life using scientific inquiry in fixing a car or gathering evidence to make an informed decision.

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FORMATIVE USE OF SELECT-AND-FILL-IN CONCEPT MAPS IN ONLINE INSTRUCTION: IMPLICATIONS FOR STUDENTS OF DIFFERENT LEARNING STYLES

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With the establishment of the Internet and World Wide Web (WWW) as part of the digital revolution, there has been, globally, a trend in which synchronous and asynchronous distance education opportunities have been made available to a greater variety of learners. The flexibility and freedom from time and attendance requirements afforded by online instruction is one of the greatest appeals for many learners. One consequence of this, however, is students indiscriminately pursuing online learning opportunities for the sake of convenience without consideration of the appropriateness of online instruction for their individual learning behaviors and characteristics (Diaz & Cartnal, 1999). Educational institutions, in an attempt to develop highly-enrolled, successful, profitable distance learning programs, are, then, accepting these students with a similar lack of discrimination. Most institutions do not perform an assessment of incoming distance education students to determine their appropriateness as online learners (James & Gardner, 1995). For those that do, most often the assessment is designed to serve only as a guide, with no formal admittance or denial policy attached to the results. This has resulted in many online courses and programs enrolling students for whom the online learning environment is less than ideal (Diaz & Cartnal, 1999), challenging teachers, administrators, technologists, and students to see that online instruction meets its potential.

The digital revolution has brought about societal change as well. It has become evident that the rate at which things change, and the unpredictability of such change, is greater than ever. Living in such a dynamic culture, citizens today must, more than ever, be able to take information from various sources and make sense of it in order to function in society. In particular, given the rate of change of cultural knowledge and norms, it is necessary that citizens have the basic skills to solve the unforeseeable problems that will occur as a result of such dynamic changes.

In light of the convergence of the challenges described above, it is important that educators develop and investigate teaching and learning strategies that will appeal to a broad variety of online learners. Select-and-fill-in (SAFI) concept maps may provide such a strategy.

The Study

Research Question

This study attempted to answer the question: *How do students of different learning styles respond to online instruction in which SAFI maps are utilized?*

Purpose of Study

The purpose of the research was to investigate the formative use of SAFI maps in online instruction and the effects their use may have on students' responses to questions in which they are required to apply knowledge contained in the maps. In particular, the interaction between such use and the four learning styles described by David Kolb's learning style model (Kolb, 1984) was considered through the development of four, illustrative cases, with the intent of identifying those styles that may be best suited to SAFI map use given their cognitive, metacognitive, and affective responses to the SAFI maps.

Theoretical Framework

Knowledge Application

The most commonly used framework through which studies on application of knowledge have been carried out is that proposed by Bloom in his seminal work, *Taxonomy of Educational Objectives* (Bloom, Englehart, Furst, Hill, & Krathwol, 1956). In Bloom's taxonomy, educational objectives are organized in a hierarchical fashion based on learner behaviors, each level requiring skills attained in the previous level in the taxonomy. Two classes of behavior, knowledge and comprehension, represent the prerequisites to application of knowledge in an attempt to solve a problem. For correct application of knowledge to occur, it is necessary that learners master the knowledge class of the domain, requiring that they have the ability to remember and recognize appropriate ideas, content, and phenomena.

Once a learner has successfully met knowledge objectives, the next class of behaviors, those requiring comprehension, must be mastered. Successful comprehension requires behaviors of translation, interpretation, and extrapolation of information based on understanding, and abstraction, of the literal message found within the communication of the content knowledge being learned. Only when these two behaviors can be successfully completed and demonstrated will a learner be able to take the knowledge learned and apply it to a unique situation without being prompted as to the appropriate abstraction necessary to complete a task or solve a given problem. Within the framework presented by Bloom, successful application of knowledge assumes comprehension and abstraction of knowledge has occurred.

Constructivism

In the years since the publication of Bloom's taxonomy, educational practice has embraced a constructivist epistemology as a referent for teaching and learning (Tobin & Tippins, 1993). The constructivist approach to instruction is designed around the notion that individual learners take experiences and build mental structures as representations or theories of the information contained in the experience. Like Bloom, constructivists believe that the learning process begins with acquisition of information. As more is learned, more effective ways of structuring experience are developed by the learner, resulting in a more complex cognitive structure that is equivalent to progress through Bloom's taxonomy. This, in turn, leads to knowledge that can be more generally applied to any problems onto which the same structures can be imposed. It is assumed, then, that learners can apply, through generalization across situations exhibiting patterns of shared elements and similarities, the theories contained in their mental structures to similar situations to complete tasks and solve problems.

Concept Mapping

From a constructivist perspective, instruction must be designed to provide individual learners with opportunities to make the connections between the new information and his or her existing cognitive structure (Ausubel, 1968; Novak & Gowin, 1984; Shavelson, Lang, & Lewin, 1993). Representation of an individual's cognitive structure is often communicated by the use of the concept map, a tool developed at Cornell University by Joseph Novak and colleagues while looking at changing cognitive structures in science students (Novak & Gowin, 1984; Novak, 1996).

There has been a great deal of research done on the use of concept maps for teaching and learning purposes. A review of the literature shows that concept maps have been found to be useful in other aspects of teaching and learning as well. Ruiz-Primo, Shavelson, and Schultz (1997) provide an extensive list of concept map components and options as they relate to use in the classroom. Used as pre-instruction advance organizers, study aids, and, most commonly, as assessment tools, concept maps, may play a valuable role in the classroom (Cliburn, 1990; Novak & Gowin, 1984; Novak, 1996;. Ruiz-Primo et al., 1997; Willerman & MacHarg, 1991).

For online educators, technological considerations make dynamic interactivity and construction of online graphic organizers a difficult, technically complex process. However, inexpensive, commercial software is available that allows the user to create maps and export them to the WWW as a static image embedded in an hypertext markup language document. With this facility, an alternate, less-investigated form of concept-map based assessment, the use of SAFI, maps, may be of value.

This process of using SAFI maps, as described by Schau and Mattern (1997), begins with an expert-created map. Then, while maintaining the integrity of the map, some of the elements of the map are eliminated. Students are then asked to fill in the missing concepts or links by choosing them from a list of terms provided, with or without distractors (Schau & Mattern, 1997). Feedback is then provided to the students based on the number of correct responses provided.

Learning Styles

The implications of available technologies are not the only obstacles to successful, instructionally sound distance education. In addition to the technical challenges of providing instruction online, distance educators must also consider the individual learner characteristics, including learning style, of their students. Learning style is of great importance in online instruction because instruction is most often conceptualized and designed well before it actually occurs, resulting in formative assessment of online practice lacking the flexibility and spontaneity of that in the classroom. Therefore, it is necessary that a variety of instructional strategies be used at the design phase such that the learning styles of all students enrolled may be complimented proactively.

Research on distance education and learning styles has been focused primarily on the relationship between learning style profile and student outcomes such as drop and completion rates, attitudes towards the learning process, and predictors of high-risk students (Diaz & Cartnall, 1999). There are many models of learning styles, each considering the cognitive, perceptual, or affective dimensions of students that explain why different students prefer learning in different manners. One of the most common models for learning style used in distance learning research is that developed by David Kolb (Diaz & Cartnall, 1999). Kolb's Learning Styles Inventory (LSI) instrument identifies students as having one of four styles: the converger, the diverger, the assimilator, and the accommodator. Figure 1 includes the dominant learning style preferences of the cases from the study within the framework of Kolb's model.

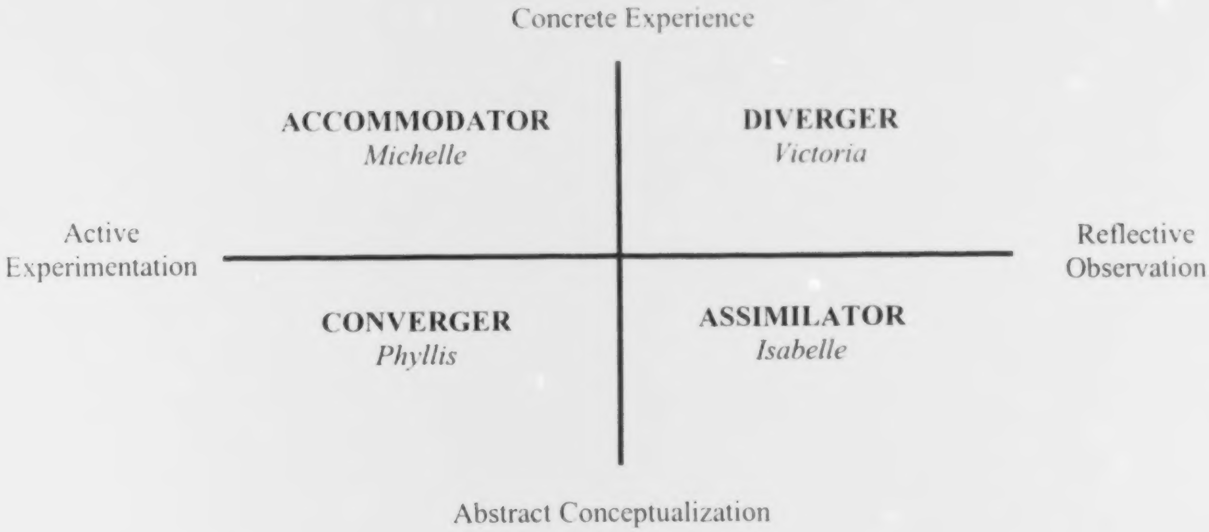
Concrete Experience
ACCOMMODATOR
Michelle
DIVERGER
Victoria
Active Experimentation
Reflective Observation
CONVERGER
Phyllis
ASSIMILATOR
Isabelle
Abstract Conceptualization

Figure 1. Case subjects within Kolb's learning style quadrants.

Given the isolated nature of online coursework, learners that require concrete experiences and are not successful at thinking abstractly have been shown to be at high-risk in distance learning environments (Dille & Mezack, 1991). These are, in Kolb's model, the diverger and the assimilator. Special consideration, then, must be given to online student learning styles. The opportunities extended by distance education cannot be taken advantage of if, during implementation, they replicate the problems found in traditional classrooms.

Formative Evaluation

Formative practice is that which explicitly or implicitly has the function of providing information in the form of feedback from which teacher and student will be able to make an informed decision with the goal of changing behavior and improving performance (Gipps, 1994; Harlen & James, 1997; Stiggins, 1991; Wiliam & Black 1996). In online instruction, communications, containing instructions to students, student responses, and instructor feedback, can then be facilitated via e-mail or a WWW-based messaging system.

The connected, structured understanding of the information within a domain, as represented in a completed SAFI map, relates directly to the hierarchical nature of Bloom's taxonomy. Application of knowledge possesses a reliance on knowledge and comprehension, though no single piece of knowledge within a discipline exists in isolation. A more complex, integrated, and connected understanding of the structure of concepts within a discipline, then, should increase the likelihood of an individual successfully applying knowledge as attempts at abstraction are enhanced by the relationships, and their subtleties, between concepts.

Therefore, use of SAFI maps, when used formatively, should improve a learner's ability to apply knowledge by providing an accepted structure to the concepts within a domain, while indicating nuances in the relationships between these concepts that are fundamental to correct, appropriate application of the knowledge reflected in the information contained in the map. When designed carefully and deliberately, they should provide online learners with opportunities to build upon and refine their conceptual understanding, leading to improved ability in applying information contained in the concepts and their relationships. This may be facilitated without advanced or complex technologies that often distract online instructors and students from the intended roles of, respectively, teachers and learners.

Despite the volume of literature on the use of concept maps in teaching and learning, there is little on the relationship between learning style and concept maps in the classroom. Though it has been found that successful concept mappers tend to exhibit an internal locus of control (Zeitz & Anderson-Inman, 1993), prefer learning through thought and reflection (Schreiber & Abegg, 1991), and have a preference for identifying the relationships between variables (Okebukola & Jegede, 1989), a defining relationship between learning style and concept mapping has not been identified. Furthermore, there is a paucity in the literature discussing research into the relationship between learning style and, in particular, use of SAFI maps.

The Research Design

Sample

The sample for the study was students that enrolled and participated, through a public, two-year community college, in an asynchronous, online environmental studies course. Technologically, the course is facilitated through a course web site, readable through any standard web-browsing software and a rich, intranet-based email system.

Design and Methodology

The research was an emergent design, collective case study in which several cases, sharing a dominant learning style, were to be described and presented as a single entity or case (Stake, 1995). However, distribution of participant cases among the four learning styles was not even. Upon receipt and validation of signed consent forms and evaluation of returned LSI-3s, nine subjects for the study were identified. Of these nine, five were assimilators, two were convergers, and the remaining two comprised of one accommodator and one diverger. Data were analyzed, therefore, using collective cases for assimilators and convergers, and individual cases for the accommodator and the diverger, as shown in Figure 1.

The study was carried out over a nine-week period, comprising one abbreviated summer session containing fourteen instructional units. This period, for the purposes of the study, was broken into two phases. Table 1 contains the data collected and the study-related activities occurring during each phase of the research.

Table 1

Phases of research with corresponding activities and data collection

PHASE	ACTIVITIES	DATA COLLECTED
I	• Prospective participants completed and returned LSI-3 and consent form	I. Learning Style
II	• Participants completed SAFI maps and correlating quiz items(Appendix A) • Participants completed Post-SAFI Survey (Appendix B) • Participants completed Post-SAFI Questionnaire (Appendix C)	II. SAFI map achievement scores III. Quiz item achievement scores IV. Responses to Post-SAFI Survey V. Transcriptions of email exchanges regarding feedback on SAFI task VI. Responses to Post-SAFI Questionnaire

Data Analysis

The general strategy of analysis of the data for this study was pattern-matching (Tellis, 1997; Trochim, 1989; Yin, 1994). Under this strategy, data collected was sorted and coded for each individual student case. Upon completion of each individual participant case, cases for each learning style were grouped and cross-compared, matching patterns of participant attitude and achievement around the SAFI map tasks found in the data. The product of this was the creation of a learning style-based case representative of the individual cases. Figure 1 identifies the four cases and their dominant learning style in Kolb's model. Once the four learning style-based cases were established, these four were then cross-compared in an attempt to answer the research question and to identify cognitive, metacognitive, or affective responses to the SAFI tasks.

Cross-Case Analysis

For the purposes of this analysis, cognitive response is evident in SAFI task achievement, quiz item achievement, and successful knowledge application. These tasks can be found in Appendix A. Also, verbatim use of SAFI elements in application is indicative of SAFI map elements being instrumental in student construction of knowledge as these elements are directly integrated into the students' cognitive structure, indicating a cognitive response to the process of completing the SAFI tasks..

Metacognitive and affective responses are evident in student responses to the Post-SAFI Survey (Appendix B) and Questionnaire (Appendix C) as well as data from student email transcriptions. Individual, independent indications of student cognitive, metacognitive and affective responses to the SAFI tasks were an integral part of this analysis.

In Kolb's model, the assimilator and the coverger lie on the abstract end of the concrete-abstract continuum that is part of his learning cycle (Kolb, 1984). However, the preference for working with abstract concepts was not reflected immediately in initial SAFI task achievement, with Isabelle and Phyllis, the assimilator and the converger, having difficulty with the first SAFI task. Victoria and Michelle, the diverger and the accommodator, were more successful at completing the maps and abstracting, from text, the concepts and their relationships such that their SAFI item responses accurately reflected the subject matter. Table 2 contains SAFI map achievement data for the cases.

Table 2.

SAFI Achievement Data

CASE	SAFI – 1		SAFI – 2		SAFI – 3		SAFI - 4	
	Number Correct	Incorrect Items	Number Correct	Incorrect Items	Number Correct	Incorrect Items	Number Correct	Incorrect Items
ISABELLE - ASSIMILATOR								
Case 1	8	1,6,8,10	12	NA	9	9,11,12	12	NA
Case 2	10	1,9	12	NA	12	NA	12	NA
Case 3	12	NA	12	NA	12	NA	12	NA
Case 4	3	1,2,3,5,6,710,11,12	12	NA	5	5,6,8,9,10,11,12	12	NA
Case 5	10	2,10	12	NA	7	3,6,9,10,12	12	NA
MICHELLE - ACCOMMODATOR								
Michelle	12	NA	12	NA	12	NA	12	NA
VICTORIA - DIVERGER								
Victoria	10	1,10	12	NA	12	NA	12	NA
PHYLLIS - CONVERGER								
Case 1	4	1,2,3,4,5,7,11,12	12	NA	12	NA	12	NA
Case 2	7	1,2,5,10,11	12	NA	12	NA	10	2,10

Number Correct = number of items answered correctly out of 12 items
Incorrect Items = specific items answered incorrectly
NA = Not Applicable

Between the first SAFI task and the corresponding quiz, all four cases completed the Post-SAFI Survey (Appendix B), which was designed to give an early sense of the metacognitive and affective impact SAFI map use may have on students. All agreed that the exercise was helpful and made them think about their own thinking. However, Isabelle and Phyllis, the more abstract-inclined assimilator and the converger, acknowledged that the SAFI task made them feel more anxious about the upcoming quiz.

Similarly, Isabelle and Phyllis disagreed and strongly disagreed, respectively, with the statement expressing that the SAFI task was enjoyable.

Michelle and Victoria, the accommodator and the diverger cases, found the SAFI task enjoyable, though neither of them found that the SAFI task showed them where they had misunderstandings or misconceptions. Similarly, Michelle and Victoria did not find the exercise to be a waste of time and felt that completing the SAFI exercise may have increased their confidence towards the upcoming quiz.

Results from the Post-SAFI Survey yielded insight into the metacognitive and affective differences between the more abstract and more concrete of Kolb's learning styles. The more concrete-oriented accommodator and diverger were more open to the task and found them enjoyable, but the metacognitive activity and awareness required to connect the task to overall learning and performance was not explicit for them. This is reflected in the lack of anxiety and admitted confidence surrounding the impending quiz. It is possible that the abstract representation of concepts and relationships reflected in the SAFI map did not have the cognitive and metacognitive value that it would to the learner with a greater affinity towards the abstract.

On the other hand, the more abstract learning styles, though not finding the task enjoyable, had made the connection between the map content and structure to the subject matter such that the anxiety and confidence towards appropriately abstracting from the SAFI map and understanding the relationships expressed in the map may have been a more conscious concern. This metacognitive activity and awareness is reflected in Isabelle's comments that "It was difficult until I stopped overanalyzing." and "I like quick answers and you did have to really contemplate the meanings of the terms and how they could be interpreted.". Unsolicited comments suggesting a metacognitive role for the SAFI task were not received from either Michelle or Victoria.

Following completion of the Post-SAFI Survey, students completed the four SAFI tasks and corresponding quiz items through the second from final unit of the course. Table 3 includes Quiz Item Achievement data for single and collective cases. Upon completion of all of these, students completed the Post-SAFI Questionnaire (Appendix C). The questionnaire was designed to assess participant attitudes, and possible changes in these attitudes, towards the relationships between the SAFI map task, the participants' interaction with the map and content, and his or her learning and perceptions of learning after having completed SAFI maps throughout the course.

Table 3

Quiz item achievement data

CASE	**QUIZ 1**			**QUIZ 2**			**QUIZ 3**			**QUIZ 4**		
	Total	Item	App.	Total	Item	App.	Total	Item	App.	Total	Item	App.
ISABELLE - ASSIMILATOR												
Case 1	90	20	1	75	10	3	100	20	1	100	20	1
Case 2	100	20	2	100	20	1	100	20	2	100	20	1
Case 3	100	20	2	90	10	4	90	20	1	85	10	4
Case 4	90	20	1	100	20	2	100	20	2	95	15	1
Case 5	80	NA	NA	75	10	4	100	20	1	90	10	3
MICHELLE - ACCOMMODATOR												
Michelle	85	20	1	100	20	2	100	20	1	90	10	2
VICTORIA - DIVERGER												
Victoria	90	10	4	90	10	3	100	20	1	95	15	1
PHYLLIS - CONVERGER												
Case 1	100	20	2	100	20	2	100	20	2	95	15	4
Case 2	80	10	2/4	90	10	2	80	20	2	75	NA	NA

NA = Not Applicable or Not Answered
Total Points Earned = total points earned out of 100 possible points
Item Points Earned = total points earned out of 20 possible points
Application: 1 = successful application using SAFI elements
2 = successful application not using SAFI elements
3 = unsuccessful application using SAFI elements
4 = unsuccessful application not using SAFI elements

Isabelle - Assimilator

Isabelle, in answering the Post-SAFI Questionnaire items, indicated strongly that she believed that the SAFI tasks helped her learn and prepare for the quizzes, writing, "I had to read all of the chapter very carefully to find the answers and in doing so I memorized many things." This metacognitive impact of the SAFI maps is evident in her recognizing what she called "the raw understanding" represented in the structure of the maps. Isabelle recognized that the SAFI maps could provide her with a framework for conceptual organization that she could use as a basis for her own cognitive structure as well.

Isabelle also reported that the SAFI map tasks improved her confidence in that they honed her "ability to recognize important elements". This is a fundamental prerequisite to successful knowledge application in Bloom's model. Despite Isabelle's positive metacognitive response to the SAFI tasks, achievement, reflecting a cognitive response, was not consistent throughout the course. Isabelle's ability to accurately apply her knowledge was often incomplete and did not use, with any regularity, elements taken from the SAFI map.

When asked if she enjoyed the SAFI tasks themselves, Isabelle was consistent with her response to the post-SAFI survey administered seven weeks earlier in which she reported that, though she didn't find the SAFI maps enjoyable, she did feel that they were helpful. Upon completion of all of the course SAFI tasks, she replied that, given a choice of doing them or not, she "would 100 percent do them", acknowledging, though, that "This exercise was a challenge for me, one that I received much satisfaction from when I was successful at completing". This indication of a positive affective response to the

SAFI maps would be expected given the preference for working in the abstract, focusing on the activities of reflective observation and abstract conceptualization, indicative of the assimilator.

Phyllis - Converger

Phyllis' answers to the Post-SAFI Questionnaire continued to reflect the ambivalence towards the SAFI tasks expressed in her answers to the Post-SAFI Survey seven weeks earlier. Phyllis' answers to the Questionnaire items intended to probe the metacognitive response from SAFI map use were minimal, indicating that Phyllis didn't use the structure reflected in the completed SAFI in a conscious comparison to her own existing cognitive structure. Though she agreed that the SAFI maps were helpful in assisting her in "connecting specific points of a chapter", there was no evidence supporting that the maps had a cognitive effect on her ability to apply the knowledge contained in them. Throughout the course Phyllis did not use, in her quiz answers, elements or relationships presented in the SAFI map. Instead, Phyllis' comments suggest a need to connect "points of a chapter" rather than the relationships between concepts presented in the chapter. This emphasis on the practical, indicative of the converger, may have influence overwhelming any potential cognitive or metacognitive response to the SAFI maps. This practicality regarding the SAFI tasks is also reflected in Phyllis' comments regarding the maps being helpful "because the work is broken down", that "there was not a lot of other stuff getting in the way", and that, over time, "it came easier to do them".

Any affective response from Phyllis was seated in her evolving ability to successfully complete the maps and not an expressed, innate interest, enthusiasm, or satisfaction towards their completion. For Phyllis, the maps were simply a task to be completed and forgotten, with no capacity or function to serve as a cognitive or metacognitive tool. Assigning this function to the SAFI tasks, Phyllis duly replied "no preference" when asked if she would complete the tasks if given the choice.

Michelle - Accommodator

Despite getting all of the items correct on her first attempt for all four SAFI maps, Michelle, throughout the course, showed a change in her attitude towards the tasks. In the initial Post-SAFI Survey, Michelle expressed feelings that, though she did not find the SAFI tasks enjoyable, she did feel that the maps were not confusing, were helpful, and had a positive effect on her sense of quiz preparation, confidence, and anxiety.

Michelle's responses to the Post-SAFI Questionnaire items were inconsistent with her initial response to the SAFI tasks. At the end of the course, she felt that the SAFI exercises did not help her learn better, that they were "just time consuming", and that she "did not use them for review at all". These sentiments were galvanized by Michelle's responses to the last two items on the questionnaire, where she confirmed that she "disliked" doing the SAFI maps and that, given the choice, she would choose not to do them.

Michelle's final response to the SAFI tasks is consistent with Kolb's (1984) model. In his learning cycle, the accommodator prefers learning through active experimentation and concrete experience, not the reflective observation or abstract conceptualization that are also components of his learning cycle and necessary for completion of the SAFI tasks.

Given this polarity, it stands that the accommodator's response to the SAFI maps would be nonexistent or negative. Michelle's cognitive, metacognitive, and affective responses to SAFI map use were negative in that it directly conflicted with her dominant learning style. Despite the fact that she was proficient and successful in completing the maps, she did not enjoy doing them. This dislike for the maps would make metacognitive growth a challenge in that the explicit recognition of the abstract structures reflected in the map would be, by nature, unpleasant for the accommodator.

Michelle's ability towards completing the SAFI tasks may indicate a cognitive affinity, but this does not necessarily indicate a cognitive response towards the tasks themselves. Rather, it may represent the fact that Michelle may have approached the map tasks with a thorough, accurate knowledge structure in place. Subsequently, it is possible that Michelle's success with the SAFI tasks may be attributed to the existence of a more solid understanding of the structure and relationships between concepts before attempting the tasks rather than a structure being developed as a result of the task.

Victoria - Diverger

Victoria, the other concrete-oriented learning style, had a more positive response to the SAFI maps. Upon completion of the final SAFI map, Victoria completed the Post-SAFI Questionnaire. Her feedback regarding the maps was consistent with her responses to the Post-SAFI Survey.

Victoria's cognitive response may be reflected in her gradual inclusion of SAFI elements into her answers to the corresponding quiz items. She felt that the exercises helped because "It put things in order and you could easily follow the different subjects and understand it better.". As Victoria worked on the SAFI map tasks, she was able to compare what was reflected in the map with her own understanding, indicating that "they helped me see the relationships between parts better". Also, Victoria expresses in her responses to one of the questionnaire items that "if I could do most of the map without the help of the book I felt like I knew the material well".

Victoria's metacognitive response to the SAFI maps may have precipitated this cognitive response. Her awareness regarding the structure of the map assisting her in better developing her own understanding would increase the likelihood that her cognitive structure more closely resemble the structure reflected by the completed map. As this occurred, Victoria would have extracted elements of the SAFI map, integrated them into her own cognitive structure, and explicitly used these relationships while applying the knowledge on the corresponding quiz items.

Kolb's model supports the evidence observed in Victoria's actions and behaviors. Unlike the accommodator, the diverger, though lying on the concrete end of the abstract-concrete continuum, prefers reflective observation over active experimentation. Victoria stated "It was sometimes like a puzzle and I liked trying to solve them". The diverger prefers looking for meaning, a key activity in SAFI map completion. This would explain why Victoria claimed to have "loved" doing the exercises and became more successful at completing them as the course progressed. This success created a positive affective response to the tasks.

Table 4 presents a summary of the results stemming from the analysis of the evidence present in the data collected during this study.

Table 4

Summary of learner responses to SAFI map use

DOMINANT LEARNING STYLE (Case)	RESPONSE TO SAFI TASKS		
	Cognitive	Metacognitive	Affective
Assimilator (Isabelle)	NA	+	+
Diverger (Victoria)	+	+	+
Accommodator (Michelle)	NA	-	-
Converger (Phyllis)	NA	-	+

+ evidence supports positive response to SAFI tasks
- evidence supports negative response to SAFI tasks
NA no consistent evidence

Discussion

Significance of Findings

This research study was designed to answer the question *How do students of different learning styles respond to online instruction in which SAFI maps are utilized?* The results of this study imply that the formative use of SAFI maps in online instruction may generate cognitive, metacognitive and affective responses from learners with different dominant learning styles as defined using Kolb's experiential learning model.

Kolb's model asserts learning style as occurring along two axes, one representing a concrete-abstract continuum and the other an active-reflective continuum. Previous research (Diaz & Cartnall, 1999; Dille & Mezack, 1991; Gee, 1990; Lee, 2000; Ross & Schultz, 1999; Shih, Ingbritsen, Pleasants, Flickinger & Brown, 1998) suggests that learners with an affinity for the abstract showed greater success in distance learning contexts. Similarly, research on learner characteristics suggests that abstract learners also demonstrate greater success with tasks requiring use of concept maps (Oughton & Reed, 1999; Reed & Oughton, 1998; Schreiber & Abegg, 1991).

Evidence collected in this study suggests a different relationship between learning style and the use of online SAFI maps. In response to the use of the SAFI maps, the learners preferring reflective activities (Kolb's assimilator and diverger), not abstract conceptualization (Kolb's accommodator and converger), were more likely to demonstrate positive responses to the tasks. However, there is a lack of research on interaction between cognitive, metacognitive and affective domains, learning style, and SAFI map use. Therefore, implications drawn from the analysis reflect consistency with theoretical constructs rather than previous research.

Cognitive response, as indicated by progressive success in SAFI completion, knowledge application, and precise, verbatim use of SAFI elements in application, was evident only in the diverger. Given the concrete, reflective nature of the diverger, this is inconsistent with previous research (Schreiber & Abegg, 1991; Oughton & Reed, 1999) indicating an affinity for abstract learning in individuals for whom interactions with concept maps are a positive cognitive experience.

Under Bloom's taxonomy (Bloom et al., 1954), one requirement for successful knowledge application is careful consideration and identification of key pieces of knowledge or abstractions within the given context. Given the tendency for the diverger to consider a situation from multiple perspectives and to use unconventional solutions (Kolb, 1999), it would stand that it would be less likely for the diverger to use elements from a provided structure that represents a conventional, accepted conceptual construct. This, however, was not the case. Evidence suggests that Victoria, the diverger in the study, readily integrated SAFI elements into her cognitive structure and then used the knowledge contained in this structure, in application.

Cognitive response to the SAFI exercises was not noted with the remaining cases. There was inconsistent evidence suggesting that a cognitive response occurred as a result of SAFI map use. Subsequently, the study was inconclusive regarding identifying a cognitive response to online, formative, SAFI map use that, in turn, influenced construction of knowledge and subsequent knowledge application.

The significance of the results from this study may lie in the evidence indicating metacognitive and affective responses to the SAFI tasks. Previous research has indicated that concept map construction may have a positive effect on student attitude and feelings towards a discipline and the coursework and tasks within that discipline. (Jegede, Alaiyemola, & Okebukola, 1990; Novak, 1990; Okebukola, 1992; Okebukola & Jegede, 1989; Roth, 1994). Schau and Mattern (1997) report that students are much more willing to complete SAFI maps over other forms of concept maps, with many students finding the tasks enjoyable. Findings from this study are consistent, with only the accommodator reporting that she did not enjoy completing the SAFI tasks.

Research also indicates that concept map construction may serve as a valuable metacognitive tool, generating confidence of knowing the subject matter in the learner and therefore reducing learner anxiety towards the subject (Jegede et al., 1990; Novak, 1990; Okebukola & Jegede, 1989; Roth, 1994). Previous research related to concept map use and affective and metacognitive reactions does not address individual learning styles and involves learners constructing maps themselves, not working from a provided structure. Nonetheless, for each of the four dominant learning styles represented in Kolb's model, evidence suggests that the affective and metacognitive responses to SAFI tasks, though not as expected, are consistent with theory and previous research and lends insight into answering the research question.

Victoria, the diverger, exhibited positive metacognitive and affective responses to the SAFI maps. Evidence also suggests that this was the case with Isabelle, the assimilator. Both of these learning style types lie on the reflective end of the active-reflective axis of Kolb's model, indicating that it may be preference for reflection upon learning, rather than abstract conceptualization of ideas, that explains the nature of their responses to the SAFI tasks. The "looking for meaning" (Kolb, 1999, p. 4) preferred by the reflective learner is the primary cognitive activity associated with completing the SAFI maps.

Phyllis, the converger, sharing with the assimilator an affinity towards working with abstract concepts, demonstrated a positive affective response to the SAFI tasks. However, evidence suggested a negative metacognitive response. This is consistent with the preference for using logical analysis typical of the abstract learner. As Phyllis is working on the SAFI task, she is carefully analyzing the relationships between concepts. This need for logical analysis is met during the SAFI task, resulting in a positive affective response to the task. However, the converger also prefers using real-world, practical experience in his or her learning. This is not part of the task of SAFI map completion and may explain Phyllis' negative metacognitive reaction to the tasks. Phyllis, as a converger, would prefer to consider her own thinking within a real-world context, not the abstract representation of the world reflected in a SAFI map. Subsequently, it may be that, though Phyllis enjoyed the activity of the tasks, they did not serve as useful tools she could employ to lend insight into her own thinking.

Michelle, the accommodator, demonstrated negative metacognitive and affective responses to the SAFI task use. It would not be expected that the accommodator, preferring to learn by experience, would use SAFI maps as metacognitive tools given the abstract nature of their representations. Michelle would rather have thought about her own thinking and understanding within a real-world context, not the artificial representation of the SAFI map. The fundamental opposition between the preferred, real-world context of the accommodator and the abstract representations of a SAFI map resulted in a negative affective response.

These results suggest that use of online SAFI maps, when used formatively, may play a particularly valuable role in generating positive responses in online learners that prefer to reflect and look for meaning over those that have an affinity for intellectually analyzing abstract ideas and their inter-relationships. It may be that the value of completing online SAFI tasks lies in the process of contemplating and making meaning of the relationships between concepts in the map, not in the product of a cognitive structure specifically reflecting the structure of concepts as they are represented in the completed map.

The study indicates a more consistent metacognitive and affective response across all cases. Given the nature of the SAFI tasks themselves, the cases representing more reflective learning styles should, by definition, prefer the activities required to complete the SAFI tasks. Evidence in the data collected supports this relationship in that the metacognitive and affective responses are the product of specific learning style preferences. The active experimentation preferred by learners at the active/experimental end of the active-reflective continuum of Kolb's model is not part of a SAFI task. This may explain the lack of evidence indicating any consistent, positive response to the tasks in these learners.

There is a scarcity of evidence suggesting a cognitive response, as indicated by achievement in knowledge application, in all of the cases. The lack of a readily definable cognitive response may be indicative of the value of process over product inherent to the SAFI tasks. The emphasis on the process of reflection may increase the likelihood of an affective or metacognitive, rather than a cognitive, response to use of the SAFI tasks. A cognitive response, the product of abstract conceptualization and development of a cognitive structure resulting from the successful completion of the SAFI map, would be evident in application of knowledge more directly including or reflecting SAFI elements. This was not the case. It may be that students were not using the completed SAFI maps as a reference for building their own cognitive structure. Rather, they were using the SAFI tasks as a mechanism to reflect and consciously consider relationships between concepts contained in the map. Within this process, the students then were building their own, unique cognitive structure that did not necessarily reflect that which was presented in the completed SAFI map.

Limitations of Study

Though attempts at maintaining quality of design and purpose for the study were made, limitations were inherent to the design. Given the situated, evaluative nature of the proposed study, credibility may be in question due to what Mertens (1998) describes as progressive subjectivity. The blind-nature identification of the cases until after course completion was designed to counter this effect, though the possibility of an evolving subjectivity in the researcher existed. The researcher kept a journal of thought as the research proceeded. This was read and reflected on during the data analysis as a measure by which evolving subjectivity or bias could be identified and checked during the analysis. Despite these precautions, subjectivity could exist within the presentation of cases and data analysis.

As with all case study research, the greatest limitations to the study involved generalizability. Participants were not randomly assigned to the group and were, through their enrollment choice and willingness to participate, a self-selecting sample of online-learners. It should be noted that the generalization to be derived from case study research is, according to Yin (1998), not a statistical but an analytic generalization. Within this analytic generalization, cases are used to illustrate or present a theory which, though context specific, will resonate with a large cross-section of readers (Stake, 1995).

The use of multiple cases for each learning style making up the learning style case was implemented to strengthen the analytic generalizations through replication and shared corroborative evidence. However, given the idiosyncratic nature of student behaviors and attitudes, the collective nature of the cases often presented an obstacle to objective analysis. As representative evidence was selected from individual cases for presentation within each collective case, the researcher had to choose which individual case best represented the larger trends and patterns that emerged from the coded data. Therefore, some data regarding individual student cases may have been excluded from the final data collection and analysis. The necessity to make such choices may have undermined the chances for greater objectivity of the data analysis.

With regard to the research results, the lack of evidence suggesting a cognitive response to SAFI map use poses a limitation inherent to the research design. A more quantitative analysis of a greater number of student responses in comparison to SAFI content would have strengthened the research design and increased the likelihood of identifying a cognitive response.

Summary

This study investigated the responses to the use of formative SAFI maps in online students of different dominant learning styles. Because of the qualitative, case study design, the ability to generalize from the study to the larger population is limited. However, given the evidence suggesting a positive relationship between the response to SAFI map use and reflective learning styles, it is not unreasonable to anticipate that data collected from future research will lend additional insights into the relationships between learning style and SAFI map use.

Though the findings in this study did not indicate a cognitive relationship between SAFI map use and learning style, the metacognitive and affective responses observed in the cases suggest that online SAFI map use may be a valuable tool for teaching and learning. The existing body of research on distance learning indicates that abstract learners typically fare better in online learning contexts. However, evidence from this study suggests that there is a particular value of online SAFI map use for reflective learners. Therefore, SAFI map use may play an inclusive role when incorporated into online instruction by appealing to a reflective, rather than abstract, learning style, providing expanded access to educational opportunities to a larger segment of the population.

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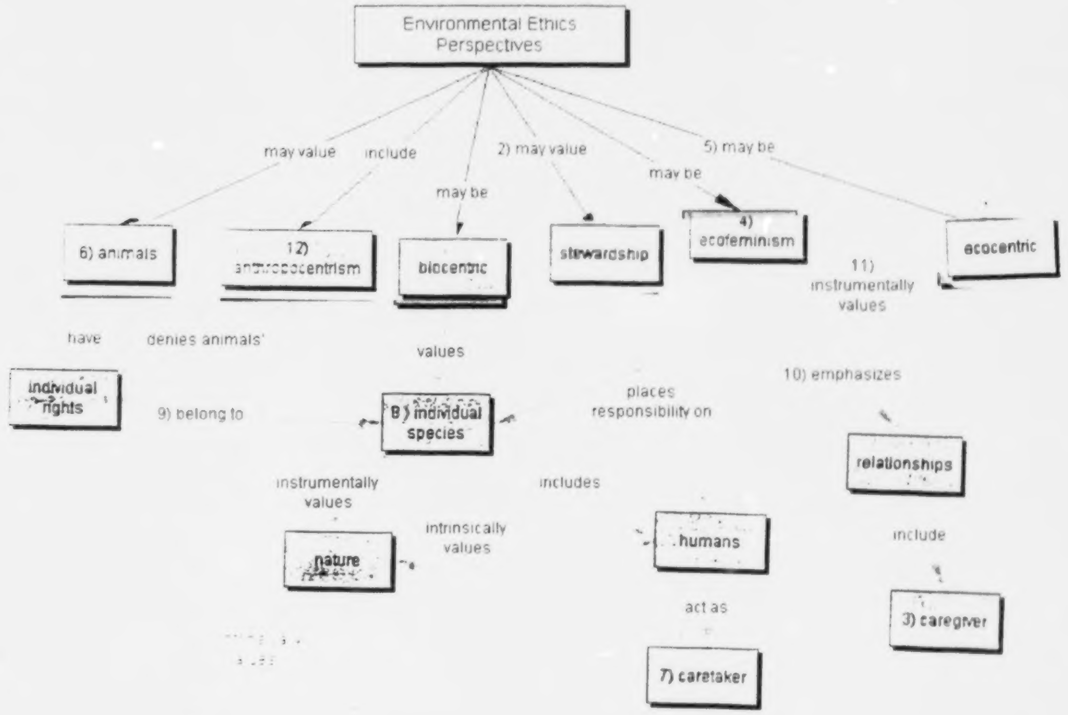
APPENDICES

Appendix A - SAFI Maps and Quiz Items

The following four SAFI maps, with items to be correctly selected and filled in acknowledged were used formatively in the study. Following each is the quiz item requiring application of content contained in each completed map.

I. SAFI Map and Corresponding Quiz Item 1 – Environmental Ethics


Environmental Ethics Perspectives
may value
include
may be
2) may value
may be
5) may be
6) animals
12) anthropocentrism
biocentric
stewardship
4) ecofeminism
ecocentric
11) instrumentally values
have
denies animals'
values
individual rights
9) belong to
8) individual species
places responsibility on
10) emphasizes
relationships
instrumentally values
includes
intrinsically values
nature
humans
include
act as
3) caregiver
7) caretaker

Quiz Item. Identify which ethical perspective can best be used to describe or explain each scenario. Explain your thinking as to why you chose this perspective.

A. A small parcel of land in the Amazon rainforest of Brazil contains a species of small flowering plant that has, for many years, been used by native populations for its reputed medicinal properties. The land is threatened by logging, and the plant in question is known to have only a small range of distribution. Environmental activists make efforts to legally protect the biologically diverse land from logging activities.

B. There are plans to reintroduce the red wolf into an area where it has locally been hunted to extinction. However, livestock herders are protesting the plans, claiming that the animals will hunt and kill their flocks. The wolves prey on small game such as rabbits, deer and wild goats, weeding out the old, injured or sick individuals and keeping natural populations of these animals, which are often found grazing alongside shepherd's stock, healthy. Wildlife biologists work with the local farmers to explain the ecology of the wolves, educating them on how the wolves and local herding activities do not have to be competitive but instead can co-exit harmoniously.

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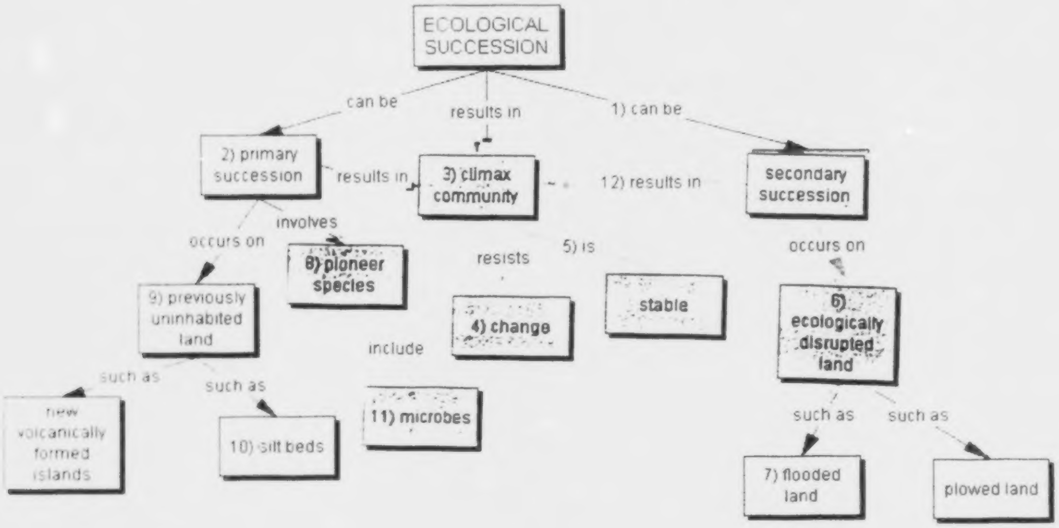
II. SAFI Map and Corresponding Quiz Item 2 – Ecological Succession


ECOLOGICAL SUCCESSION
can be
results in
1) can be
2) primary succession
results in
3) climax community
12) results in
secondary succession
involves
occurs on
8) pioneer species
resists
5) is
occurs on
9) previously uninhabited land
4) change
stable
6) ecologically disrupted land
include
such as
such as
11) microbes
such as
such as
new volcanically formed islands
10) silt beds
7) flooded land
plowed land

Quiz Item. In 1980, Mount St. Helens erupted in Washington State, spewing over three cubic kilometers of ash out of its crater in the process. The ash fell, creating a thick blanket that wiped out all living things in the area immediately around the volcano. Describe, in a few short sentences, the ecological succession that you would expect to occur after this blast. Also, is this a primary or secondary succession?

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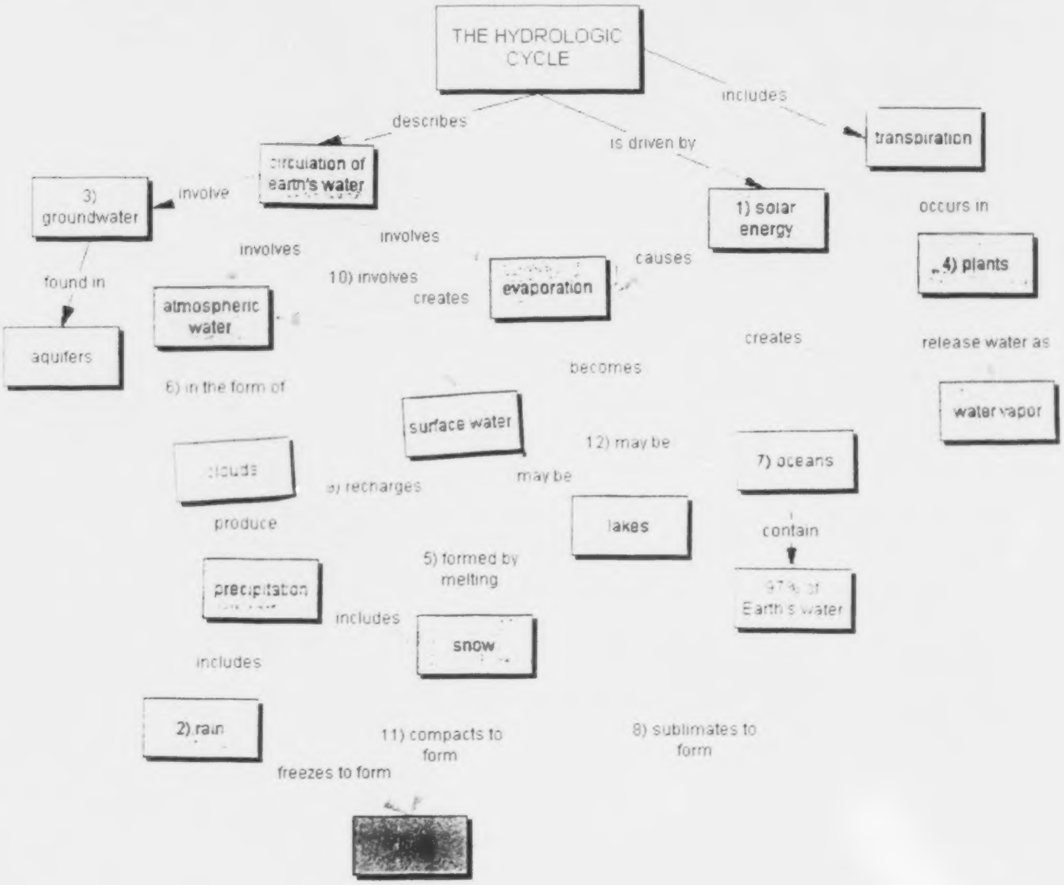
III. SAFI Map and Corresponding Quiz Item 3 – The Hydrologic Cycle


THE HYDROLOGIC CYCLE
describes
includes
is driven by
circulation of earth's water
transpiration
3) groundwater
involve
1) solar energy
occurs in
involves
involves
causes
4) plants
found in
10) involves
creates
evaporation
atmospheric water
aquifers
creates
release water as
6) in the form of
becomes
surface water
water vapor
12) may be
7) oceans
clouds
9) recharges
may be
lakes
produce
contain
5) formed by melting
precipitation
97% of Earth's water
includes
snow
includes
2) rain
11) compacts to form
8) sublimates to form
freezes to form

Quiz Item. Describe the typical path a water molecule might follow through the hydrologic cycle from the ocean to land and back again, being sure to address residence time. Then, predict the path in the hydrologic cycle for the same molecule if global climate were to cool significantly. Feel free to be creative, but your prediction much make logical, scientifically-accurate sense.

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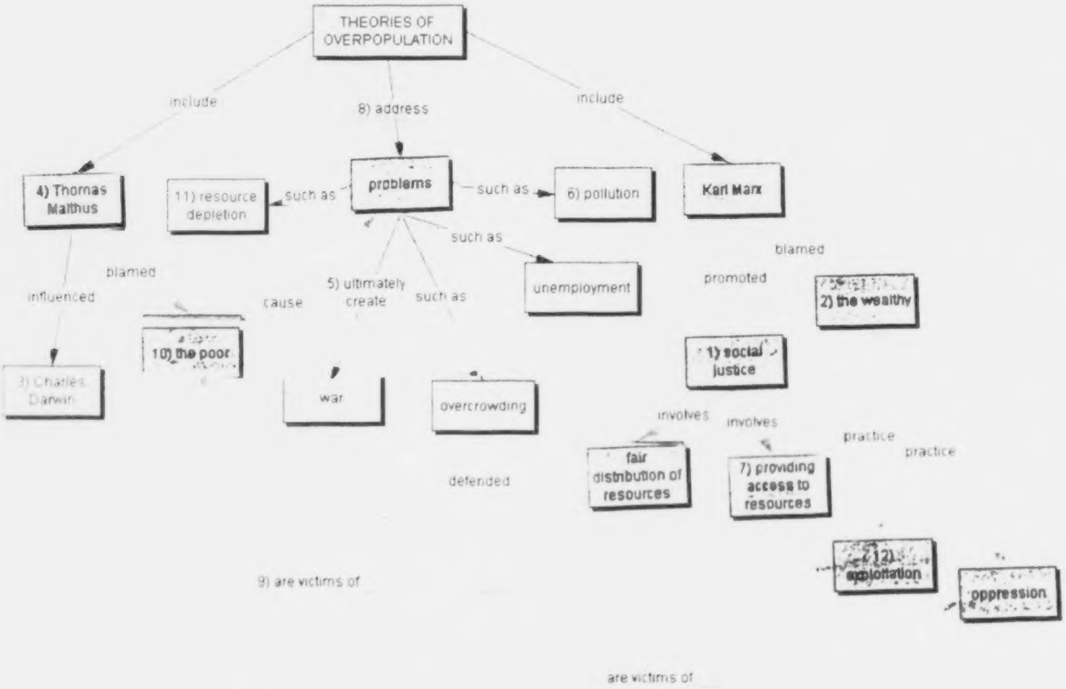
IV. SAFI Map and Corresponding Quiz Item 4 – Theories of Over-Population


THEORIES OF OVERPOPULATION
include
8) address
include
4) Thomas Malthus
11) resource depletion
such as
problems
such as
6) pollution
Karl Marx
such as
blamed
influenced
blamed
cause
5) ultimately create
such as
unemployment
promoted
2) the wealthy
10) the poor
1) social justice
3) Charles Darwin
war
overcrowding
involves
involves
practice
practice
fair distribution of resources
7) providing access to resources
defended
12) exploitation
oppression
9) are victims of
are victims of

Quiz Item. Imagine that, through some miraculous technological advance, resources on the planet became infinite and made available to everyone equally. Predict what effect would this would have on global populations based on both Marx's and Malthus' theories of overpopulation.

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Appendix B - Post-SAFI Survey

You have just completed a SAFI map exercise on ethical principles. Below are ten statements about this exercise. Please rate, using the numeric scale below, the extent to which you agree with the statement. Thank you.

1 - Strongly Agree
2 - Agree
3 - Disagree
4 - Strongly Disagree

1. Completing the SAFI map exercise was helpful.
2. Completing the SAFI map exercise made me feel more anxious about the upcoming quiz.
3. Completing the SAFI map exercise helped me review in preparation for the quiz.
4. Completing the SAFI map exercise clarified things that were unclear to me.
5. Completing the SAFI map exercise was a waste of time.
6. Completing the SAFI map exercise was enjoyable.
7. Completing the SAFI map exercise made me feel more confident about taking the upcoming quiz.
8. Completing the SAFI map exercise confused me.
9. Completing the SAFI map exercise showed me where I had misunderstandings or misconceptions.
10. Completing the SAFI map exercise made me think about my own thinking.

Appendix C - Post-SAFI Questionnaire

Throughout this semester, you have been completing SAFI map exercises on a variety of topics. Please answer the following questions regarding the exercises. Be as honest, open, and specific as possible in response to these questions. You have my guarantee that in no way will your responses to any of these items impact your grade or status in the course. Thank you.

1. Do you think that the SAFI map exercises helped you learn better? Why or why not?
2. Did you find that the SAFI map exercises were helpful to you when reviewing things covered in the course? Why or why not?
3. Do you think that completing these SAFI map exercises helped you do better on your weekly quizzes? Why or why not?
4. Did these exercises make you feel more or less confident about how well you knew the material? Why or why not?
5. Would you say you generally liked or disliked doing the SAFI map exercises?
6. If you were given a choice of doing or not doing the SAFI exercises, would you choose to do them?

TEACHER EXPLANATIONS FOR DISCOURSE VARIATIONS IN ELEMENTARY SCIENCE METHODS

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Teacher Explanations for Discourse Variations in Elementary Science Methods

The development of a scientifically literate society is dependent on effective communication. Accordingly, the *Benchmarks for Science Literacy* (the Benchmarks) (American Association for the Advancement of Science [AAAS], 1993), which defines science literacy goals for United States students K-12, contains an entire section on communication skills. One of the skills described in the Benchmarks is that "students should be able to participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarifications or elaboration, and expressing alternative positions" (p. 297). The ability of students to achieve this goal is dependent on a teacher's ability to incorporate such opportunities into lessons. Moreover, the National Science Education Standards (National Research Council [NRC], 1996, 2000) state the importance of learning to teach through inquiry. As part of learning through inquiry, teachers need the experience of "proposing answers, explanations, and predictions; and communicating the results" (NRC, 1996, p. 23), often accomplished via classroom discourse. Additionally, classroom discourse is necessary for teachers to determine what the students understand and misunderstand, what they are thinking, and what they are learning (NRC, 2000).

The nature and the function of the discourse can determine the extent to which classroom discussion is inquiry-based, which is a critical characteristic of science education (NRC, 1996, 2000). "The discussion leader must find a way to teach that is neither too dominant nor too reserved" (Brookfield & Preskill, 1999, p. 194). Teachers need to demonstrate how to challenge, clarify, and elaborate ideas; yet, they need to "allow the children to take more control of what is said, when it is said, and how it is said" (Bloom, 2000, p. 90). For this to occur, teachers need to help students understand the nature and functions of classroom talk (Bloom)

We believe that a teacher preparation program must therefore model and teach how to facilitate high quality classroom discussion. To do so, science methods instructors must examine, understand, and explain their own roles, intents, and actions during classroom discussions. Thus, one of the first steps in improving our preparation of teachers' skills in leading discussions is to understand and explain science classroom discourse as it occurs in science teacher education courses.

Literature Review

The study of discourse is often framed within a sociocultural approach to learning, which claims that individual thinking is situated in cultural, historical, and institutional contexts (Wertsch & Toma, 1995). Studying language involves understanding not only the words, but also the intentions of those engaged in the dialogue. According to Bakhtin (1981), "Language is not a neutral medium that passes freely and easily into the private property of the speaker's intentions; it is populated—overpopulated—with the intentions of others" (p. 294).

Lotman (1988), a semiotician, has argued that functional dualism is characteristic of all texts (including utterances, written words, and nonverbal texts such as costumes). In Lotman's view, texts have both univocal and dialogic functions, where the univocal focuses on conveying meaning and the dialogic on generating meaning. Wertsch and Toma (1995) apply this notion of textual dualism to the analysis of classroom discourse.

> It is reasonable to expect that when the dialogic function is dominant in classroom discourse, pupils will treat their utterances

> and those of others as thinking devices. Instead of accepting them as information to be received, encoded, and stored, they will take an active stance toward them by questioning and extending them, by incorporating them into their own external and internal utterances, and so forth. When the univocal function is dominant, the opposite can reasonably be expected to be the case. (p. 171)

Nystrand (1997), in thinking specifically about classroom discussion, illustrated how functional dualism occurs through two types of discussion, dialogic and monologic, which require different epistemic roles for students. Dialogic discussions contain statements that "respond to previous utterances at the same time they anticipate future responses" (p. 8). Such discourse is "structured by tension…as one voice 'refracts' another" (p.8). Bakhtin (in Todorov, 1984) required the dialogical semantic relationship to be structured by "two verbal works, two utterances, in juxtaposition" (pp. 60-61). The utterances express the author and the respondents and thus establish multivoiced discourse.

In contrast, during monologic discussions, teachers "'prescript' both the questions they ask and the answers they accept, as well as the order in which they ask the questions" (Nystrand, 1997, p. 12). Teachers often thwart dialogue by evaluating student answers instead of responding to ideas. Lemke (1990) and others have referred to this discourse genre as Triadic Dialogue or QAE (question, answer, evaluation). In Bakhtinian terms, "there is no second voice alongside that of the author" (in Todorov, p. 63); others' utterances are framed within the voice of the original author creating a singular context and a singular semantic orientation.

In efforts to apply these theoretical frameworks, science educators have studied multiple aspects of classroom discourse. These include conceptual understanding as expressed in discourse, types of discourse in science classes, the nature of argument, and the influence of teacher knowledge on discourse. The studies have examined elementary, secondary, and collegiate classrooms, and have found, regardless of the level, that opportunities for discourse in the science classroom are limited. For example, researchers have studied student conceptual understanding in the context of classroom discourse at the elementary (Varelas & Pineda, 1999), middle (Varelas, 1996), and high school levels (van Zee & Minstrell, 1997). Others have focused on the nature of teacher questions and response strategies (e.g., Tobin, 1984; van Zee & Minstrell, 1997). However, these studies virtually ignored the types of discourse present in science classrooms and the roles and intents of the teacher.

Other researchers have tried to delineate the types of discourse that occur in science classrooms. Lemke's landmark study (1990) demonstrated teachers' over reliance on the monologic in science classrooms, by documenting a preponderance of Triadic Dialogue. Gee (1997) identified types of science talk—Designing, Discovering, and Explaining—that occurred in a second grade classroom. Both Lemke and Gee argue for making science language a more explicit part of classroom practice. Kelly and Chen (1999) extended this argument by examining oral and written texts in high school physics. They demonstrated that student use of scientific language was related to the context of the classroom—both the social practices that had been established and the nature of the discourse activity.

Another line of research in the discourse literature has examined the nature of argument in science classrooms. Driver, Newton, and Osborne (2000), among others, posited that argument is central to science education. Researchers have examined both students' abilities to engage in argument and the opportunities they are provided to do so. Sorsby (1999) found that elementary students can argue orally to clarify, reconcile, and persuade. Bloom (2000) confirmed this in a study of middle level students' argumentation about density. In a study of high school genetics (Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000), students did develop arguments during a problem solving task, using more claims than justifications or warrants. In an examination of student and teacher questioning, van Zee, Iwasyk, Kurose, Simpson, and Wild (2001) asserted that student questions occur more frequently when specifically elicited during the discussion, when a KWHL chart is constructed as part of the discussion, during brainstorming experiences, and during guided closure. Student generated inquiry discussions can be elicited by assigning facilitator roles to the students and explicitly describing the desired discourse to the students (van Zee et al., 2001). Unfortunately, such opportunities for argument in science classrooms are often limited (Newton, Driver, & Osborne, 1999).

A number of studies have examined the ways in which teacher knowledge and classroom discourse influence opportunities for learning science. Carlsen (1992, 1993) found that a teacher's subject matter knowledge affects the types of discourse that occur in high school biology classrooms, with less knowledgeable teachers more apt to limit opportunities for dialogue. In biology and chemistry classrooms, Carlsen (1997) again documented that teacher subject matter knowledge was a factor in shaping the argument patterns that occurred. Cunningham (1997) demonstrated that teachers' sociological understanding of science influences how they "structure their classrooms to convey messages to their pupils about students' abilities to do science and the sources of scientific information" (p. 24). For example, in a study of a high school chemistry teacher (Moje, 1995, 1997), the social norms the teacher built communicated that science is precise and authoritative, with only specific styles of discourse allowed. Crawford, Chen, and Kelly (1997), in the context of a high school physics course, found that students appeared to know less and were less willing to offer explanations to what they perceived as a knowledgeable audience (teachers) versus a less knowledgeable audience (fifth graders).

Thus it becomes clear that teachers have high levels of control over the types of discourse that occur in science classes.

Science education researchers have also documented the functional dualism of discourse in science classrooms. Mortimer (1998) examined the oral discourse in a high school science class in the context of discussing models of matter. He found that the alternation of what he called authoritative (Lotman's univocal) and persuasive (Lotman's dialogic) was an important feature of classroom talk. In a microanalysis of a high school discussion about density, Mortimer and Machado (2000) claimed that this alternation allowed students to "move successively from ignore to perceive, negate, admit, and compensate for a disturbance" (p. 438). Scott (1999) also found a dialectic relationship between authoritative and dialogic functions in high school science discourse related to chemical reactions. Scott regarded the authoritative/dialogic functions as two dimensions along a continuum of classroom discourse, believing that "individual student learning in the classroom will be enhanced through achieving some kind of balance between presenting information and allowing opportunities for exploration of ideas" (p. 14). However, he provided no guidelines for what the proper balance should be.

The science education research literature on classroom discourse is thus rich and varied. Most of it, however, has been undertaken within the context of high school science. If we want to help build a culture of dialogue in science teaching, we also need to understand discourse in the context of teacher education. Few studies of discourse have been conducted in undergraduate science teacher preparation programs. Koballa (1984, 1985) examined student persuasive communication in science courses for preservice elementary teachers and its influence on attitude changes toward energy conservation. Van Zee (2000) analyzed student-

student interaction during a science discussion in an elementary science methods course. She determined that practices of teacher quietness and distributed authority fostered inquiry.

While these studies looked at discourse function, they did not examine the monologic/dialogic nature of the discourse per se. Furthermore, they focused only on discourse related to science content. The necessity for our research stems from the void in the literature regarding discourse in an undergraduate teacher education setting, from both the perspective of the types of discourse that occur and the intentions of the instructor in guiding the discourse. Additionally, the need exists for the study of discourse in both the contexts of science and pedagogy instruction.

Research Design

This study was theoretically framed by a constructivist perspective (Schwandt, 2000). Our research was guided by the relativistic ontological assumption that realities are multiple, constructed, and holistic (Lincoln & Guba, 1985). Reality is a socially and experientially constructed entity and its form and content depend on those who hold the construction (Lincoln & Guba, 2000; Schwandt, 2000). Within the constructivist framework exists an epistemological belief that the inquirer and the object of inquiry are interactively linked, influence one another, and become inseparable (Lincoln & Guba, 1985, 2000). Additionally, the methodological perspective of a constructivist paradigm is that inquiry is hermeneutical and dialectical. Investigators and participants participate in dialogue among themselves and with the data to develop "more informed and sophisticated reconstructions" (Lincoln & Guba, 2000, p. 170), interpreted using hermeneutic techniques. Because "understanding is always interpretation and hence, interpretation is an explicit form of understanding" (Gadamer, 1994, p. 307), varying constructions were compared, contrasted, and eventually understood through a dialectical interchange. The final rendering, "one interpretation among multiple interpretations of a shared or individual reality" (Charmaz, 2000, p. 523), includes the etic construction of the investigators informed by the emic constructions of the participants and is more sophisticated than any antecedent constructions.

In accordance with the constructivist theoretical framework, we utilized an interpretive research design (Denzin & Lincoln, 2000). The design permitted flexibility "to allow for discoveries of new and unexpected empirical materials and growing sophistication" (Denzin & Lincoln, p. 368). An important aspect of our interpretive research design was self-study.

The two major purposes of teacher self-study deal with "refining, reforming, and rearticulating" education (Cole & Knowles, 1996, p. 1). The first purpose of self-study is personal professional development. Self-study of this nature aims at improving pedagogical practices. The second purpose of self-study is to enhance understanding of teacher practices, processes, and contexts. This form of self-study aims to advance knowledge about teaching and its settings. Obviously, the two purposes are not mutually exclusive, although, typically, one predominates. At a minimum, self-study requires "taking an inquiry stance towards our practice" (Raphael, 1999, p. 49). This requires developing teaching methods, practices, and curriculum, then implementing them, followed by studying them.

Paulsen and Feldman (1995) advocated using self-study to address the challenge of improving college level teaching. They concentrated on the need for faculty members to improve instruction by studying themselves and discovering how they "interact with their own environment" (Paulsen & Feldman, p. 9). Moreover, Paulsen and Feldman claimed, "the best source of informative feedback available to most instructors is themselves" (p. 9). Consequently, the advancement of university teaching requires self-study.

The self-study aspect of our design allowed for a strong emic perspective and an "insider's" individual interpretation of the research. In addition to standing alone, the emic perspective interweaved with the perspectives of the other members of the research team. The final constructions of our individual and shared realities were strengthened by the emic perspective gained from self-study.

Research Questions

As part of a teacher-as-researcher project and in an effort to better understand her own teaching style and efficacy, Hubbard undertook an informal self-study of her teaching during an elementary science methods class. From this initial study, she established that she used discussion techniques differently when teaching science content as compared with teaching pedagogical topics. To better define and understand these differences, Newman and Abell joined Hubbard in a formal study of her teaching practices in the elementary science methods course. We undertook a systematic inquiry of classroom discourse to examine the following research questions: How does classroom discourse in an elementary science methods course differ between teaching pedagogy and teaching science content? To what extent are pedagogy and science content taught dialogically and/or monologically in the undergraduate elementary science teaching methods course? How does the instructor account for such differences? The focus of this paper is on the final research question.

Research Setting and Participants

The elementary science methods course in the study is built on a reflection orientation (Abell & Bryan, 1997) that provides opportunities for students to build theories of science teaching and learning as they: (a) observe others teach, (b) reflect on their own teaching, (c) read expert theories, and (d) examine their own science learning. Students engage in both science content explorations and pedagogy activities in the class. We chose this setting because it was the course that Hubbard studied informally, and we previously have examined several different aspects of science teacher preparation in this course (Abell & Bryan, 1997; Abell, Bryan, & Anderson 1998; Abell, Martini, & George, 2001; Abell & Smith, 1994). The course section in this study was somewhat unusual in that it occurred as an intensive 8-week program during the summer with only 12 students, 9 females and 3 males. All of the students had just completed their third year in the teacher education program.

Role of the Researchers

Hubbard, the course instructor, taught elementary and middle school science for five years and had taught the methods class the previous two semesters. In addition to teaching the course, Hubbard participated in formal and informal interviews during the study.

Newman served a peripheral membership role in the course taught by Hubbard. In a peripheral membership role, researchers feel "an insider's perspective is vital to forming an accurate appraisal of human group life, so they observe and interact closely enough with members to establish an insider's identity without participating in those activities constituting the core of group membership" (Adler & Adler, 1998, p. 85). Newman taught high school science for 10 years and during that time regularly aided elementary teachers with science instruction. Moreover, he spent one year as supervisor of science for a suburban school district and has taught several teacher education and science courses at the university level. Newman regularly attended class, closely observed activities, took field notes, and interviewed participants without engaging in course activities. As the project progressed, Newman maintained the stance of empathic neutrality (Patton, 1990) so as to have minimum influence on the classroom functions. All three researchers participated in data analysis and writing.

Data Collection Techniques

We used a variety of data collection techniques in this study, including peripheral membership observation, interviewing, videotaping, audiotaping, and collection of documents.

Peripheral Membership Observation

Newman visited the classroom for six of the eight weeks the class met. The other two weeks, the students participated in field experience and met to prepare lessons. When Newman was in the classroom, he observed the class and took field notes that contained, but were not limited to, descriptions of the environment, participants, activities, researcher's feelings, interpretations, and reflections.

Interviews

Weekly informal discussions were used to ascertain the teacher's plans and goals regarding science and pedagogy instruction, specifically with reference to the use of discourse. Weekly follow-up discussions addressed the teacher's feelings and attitudes about the completed lessons. After each observed class meeting, Newman interviewed Hubbard regarding her use of discourse during the lessons with specific attention to science/pedagogy and monologic/dialogic issues. We developed interview protocols and reconstructed them following the guidelines for interview guide approach and standardized open-ended interview from Patton (1990). We also conducted informal student interviews as necessary to better address our research questions.

Videotaping

Videotaping of the lessons began once Newman was established in the classroom as a peripheral member. One camera, focused on the instructor, recorded all classroom activities. Additionally, we used the videotapes to elicit teacher responses during interviews.

Audiotaping

We used three recorders during classroom observations, one for each group of students. When the class met in large group discussions, we used one recorder to supplement the field notes and videotape recording. We also recorded all post-class interviews.

Collection of Documents

We collected copies of lesson plans, relevant handouts, and student work deemed important to the study.

Data Analysis

Multiple data sources, field notes, class transcripts, and interview transcripts, were used throughout the study and allowed triangulation. Field notes and transcripts of classroom discourse were the primary data sources. Data analysis began in conjunction with data collection and continued through the write-up phase of the project. In the analysis of the discourse data, we used constant comparative methods (Glaser, 1992), reading and rereading the data and comparing segments for similarities and differences using coding which reflected the concepts each segment exemplified (Patton, 1990). This process of open coding progressed until no new concepts emerged from the data. We revisited the data once it was coded to ensure that the coding was focused to the research questions guiding the study. Each research team member independently analyzed the data. We then came together as a team and discussed patterns, offered confirming and disconfirming evidence, and generated assertions grounded in the data.

The techniques used to analyze and interpret the data are rooted in the philosophy of hermeneutics and appropriate given the theoretical frame of constructivism. The study was hermeneutical in the sense that the participants (especially Hubbard) were interpreting teaching situations, and the researchers were interpreting the teacher's interpretations to establish deeper understanding and collective meaning (Patton, 1990). Interpretation and understanding are dialectically linked; thus, the participants' interpretations are influenced by their beliefs, values, and prior experiences. Analogously, our interpretations of the participants can be understood only in the light of our own beliefs, values, and prior experiences.

After mapping the videos and discussing the data, we established three major discourse focal points for detailed analysis: demonstrations, open-ended discussions, and class consensus discussions. For each discourse format, we selected an example in which science seemed to be the predominant content and an example in which pedagogy seemed to be the predominant content. We then transcribed the six segments and determined speaking patterns, who spoke when and how often. After establishing tentative categories for function of each utterance, we individually recoded each transcript. Each researcher developed new codes as needed, which were later added to the coding scheme. This iterative process of individually recoding and collectively interpreting the data continued throughout the study. Using patterns of speaking, functions of utterances, and vocality, we labeled sections of each transcript identifying to what extent the section was science and/or pedagogy and monologic and/or dialogic. Upon completion of analysis for science/pedagogy and monologic/dialogic, we coded the classroom and interview transcripts for intent.

Results

Distinguishing between science and pedagogy was not simple in an elementary science methods course (Newman, Hubbard, & Abell, 2001a). The two content areas were so intertwined that they were difficult to differentiate. Moreover, what appears to be one content area could be identified as the other based on the intents of the participants and/or the perspectives of the students or researchers.

Similarly the monologic/dialogic distinction was not always clear. When a high incidence of teacher voice was observed, the resulting discourse was not necessarily monologic. Analogously, a large proportion of student voices did not always indicate dialogic discourse (Newman et al., 2001a). Moreover, speaking patterns alone were insufficient tools for analyzing the research questions; issues of function, voice, and intent became important in describing the discourse. Given all of these variables to consider, we were unwilling to delineate a discourse sample as purely monologic or dialogic. Thus, we agree with Scott (1999) that the monologic/dialogic nature of discourse is better described as a continuum than as a dichotomy (Newman et al., 2001a).

Three whole-class discourse formats occurred regularly in the course, in both science content and pedagogy contexts: open-ended discussions to share ideas, discussions to reach consensus, and demonstrations. In earlier work (Newman et al. 2001a; 2001b), we identified the discourse characteristics of six class discussions, one of each format for science and pedagogy. A summary of these results precedes each of the following sections to establish the necessary context for the instructor's explanations of the discourse.

Open-ended Discussions

The two talks that represent open-ended discussion were a science talk (Gallas, 1995) about the moon and a pedagogy talk, a discussion about science talks as an instructional strategy. These segments were easily designated as science content and pedagogy, respectively, but the line between monologic and dialogic seemed blurred (Newman et al., 2001a). Both segments initially appeared dialogic; however, after deeper analysis, we identified the pedagogy segment, in spite of multiple speakers, as containing significant monologic characteristics because we had difficulty establishing whose voice, the teacher's or the students', was emphasized (Newman, et al., 2001b).

Because the students directed the talk and discussed ideas that were important to them, Hubbard described the science talk as involving student voice more than teacher voice. In a later interview, she also acknowledged the concurrence of her intents and the students' intents, "After the class finished, I was pleased with the outcome. I felt that it had been a good day because the students' goals for the day had aligned with my goals for the day, and together we had achieved them." Hubbard's intent of engaging the students in dialogic discourse and the students' willingness to comply with this plan resulted in a generative discussion.

Hubbard's intent for the pedagogy open-ended discussion was for the students to socially construct knowledge about using science talks as an instructional strategy. The students had already participated in the moon science talk and had seen a video of a teacher leading a discussion. When contrasted with the science talk, the teacher role differed dramatically. In a post-class interview, Hubbard stated,

> I had hoped that the students would speak as freely about pedagogy as they did about their ideas about the moon, but there was not the same vigor in the discussion. I never achieved the goal I had intended because the students had something else in mind.

> The discussion moved rapidly to a discussion of classroom management with these types of talks or with science in general.

Hubbard acted in the role of the teacher rather than of a participant during this discussion because she spent much of her time steering the discussion towards instructional strategies and away from classroom management. Accordingly, this discussion was less dialogic than the science talk (Newman et al., 2001b).

When explaining the differences between the science talk and the pedagogy talk Hubbard began by addressing her content knowledge as related to the science talk.

> The science talk was very dialogic because I know a lot about the moon and I knew I could just sit back and let them try and figure some stuff out because I understood enough to figure out how to teach them. Additionally, my goal was not that they come away with total understanding, and I was okay not being able to answer some of their questions due to the fact that I know I learn more each semester, and I feel comfortable not knowing everything and having to look it up.

She then noted a connection between her relatively high level of understanding about the moon and the students' lack of understanding.

> Oddly, during the science talk, they were completely dialogic, but knew little about the moon. I believe this is due to my content comfort level again. First, they perceived my comfort with the situation. (I think this is a big deal no matter the age level.) If the teacher is calm, smiling and basically at ease with the students, they have freedom to figure out the material. If they perceive that you are stressed, they wonder what they have done wrong. So in this case, students' lack of content knowledge didn't matter because mine was strong and comfort took over.

Hubbard also remarked on how a teacher can work around the difficulties presented when students lack desired science content knowledge.

> I do believe that a lack of science understanding can be compensated if the teacher is number one, aware of the lack of knowledge (like I know they don't know the moon) and number two, if the teacher is comfortable with that and number three, if the

> students perceive that the teacher is comfortable with the students taking time to figure it out with no fear of retaliation or grade lowering, etc. This is true about the science talk with the moon. However, I have been in classes (as a student) where this was not the case. It became hostile and monologic.

When focusing on the pedagogy talk, Hubbard shifted her attention from her students' science experiences to their lack of teaching experiences.

> The pedagogy talk about science talks is huge with regard to the students' lack of experience in teaching. They have so few teaching experiences that their main focus (as is and probably should be the case with young teachers) is on management. As a result, our intents are not aligned and some monologue ensues as I attempt to have them go deeper. Eventually I think I gave in because we were running out of time for this part of my lesson and I'd hoped they'd wrap it up. But if you notice there is some "barreling" on their parts as they try to run me down (much as I try to run them down at times when I want my way) and they talk until I give in!

In Hubbard's view, the students were unable to get to the important part of the discussion, at least from the teacher's perspective, of the uses and purposes of science talks as a teaching strategy. The students became entrenched in their need for understanding how to deal with classroom management and discipline issues during whole class discussions. The students were so adamant about this need that Hubbard was verbally "run down," and her efforts to shift the direction of the discussion resulted in higher monologic character than planned.

Differences in the nature of the two talks are grounded in two major themes, content knowledge and student experiences. While the students lacked knowledge about both science and pedagogy, Hubbard felt this issue only restricted the pedagogy talk. She indicated that the students' lack of pedagogical experiences in addition to their lack of pedagogical knowledge lead to the more monologic character of the pedagogy talk. In contrast, the students have more experiences as science learners than pedagogy learners and thus were able to adapt during the science talk despite their deficit in content knowledge. Another possible explanation might be that the students could not redirect the discussion to "how do you" issues during the science talk because they were participating in an inquiry study about the moon, and thus were personally experiencing those issues. A third issue, time constraints, is mentioned in Hubbard's explanations regarding the pedagogy talk. This issue seems linked to the differing intents, the teacher's intent to discuss a pedagogical tool and the students' intent to discuss classroom management.

Class Consensus Discussions

The discussions we selected for this discourse focal point had the purpose of reaching class consensus on a specific topic after the students had talked about it in small groups. In the conversation we labeled as pedagogy, the class discussed the use of portfolios in a science classroom. In the other conversation, labeled science, the class discussed their understanding of earth-moon processes.

Although punctuated by frequent instructor comments, this pedagogy talk appeared to be high in dialogic character. Most of the questions were open-ended and Hubbard's contributions were more as a participant leader rather than teacher (Newman, et al., 2001a). At the beginning of the discussion, Hubbard expressed her two instructional goals for her students: (a) communicating what they learned about a student, Ray, by looking at his portfolio; and (b) determining what other information and artifacts they would like in the portfolio to better understand Ray as a student. After completing the first goal, the discussion strayed from Hubbard's intended goal of determining other artifacts the students would like to have in the portfolio, and the discourse converted from highly dialogic to highly monologic. Hubbard explained the transition as a function of her lack of comfort with teaching pedagogy, especially portfolios (Newman et al., 2001b).

In contrast to the portfolio discussion, the science consensus discussion about the moon was almost entirely QAE (Newman et al., 2001b). Throughout this talk, Hubbard constantly asked questions that had only one answer and tried to get the students to figure out what she already knew and to say the answer aloud (Newman, et al., 2001a). After having students model three main points and "feeling they were comfortable with them," Hubbard gave the students a problem to solve in small groups. After this small group discussion, an open-ended, student-controlled whole class discussion ensued about what the students thought and why they believed their constructs.

Both of these class discussions contain transitions between highly monologic and highly dialogic character. Hubbard tried to explain the discourse extremes and transitions.

> With talking about Ray's portfolio, it begins dialogic when we are on comfortable ground. They had experience looking at work and evaluating what the student knows. However, when asked to apply this or step further, they were unable to do so and wanted to go back to what Ray knew. I fought this with questions, which led us to a more monologic discussion because they just didn't know how to meet my expectations. They knew how to evaluate from other experiences, but they could not determine what else was needed for complete understanding of the student.

In an interview with Newman, Hubbard discussed her own experiences and content understanding regarding portfolios.

> The portfolio discussion is a good example of how my content knowledge influences discussions. I'll agree with you now that I do know more than I think I do, however, a lot of this dialogue came as a result of my own comfort with my self-perceived lack of knowledge. I felt like it was okay to not know about portfolios because everyone has a different view. It's kind of like saying you have to understand favorite colors. Well, duh, you can't, everyone

> is different. I can list several choices, and I'm okay if people disagree.

In post-class interviews, Hubbard expressed that she did not understand the portfolio process. During the analysis process, however, Newman and Hubbard discussed her extensive experiences with portfolios and debated whether her comfort was with her lack of knowledge or with her understanding of the inherent flexibility of portfolios. Her current view seems to support the latter.

For the science consensus discussion on the moon, Hubbard described the purpose of the discussion as "providing the students with the tools I felt they needed to modify their constructs about the moon; the discussion was not aimed at their social constructions of knowledge." She controlled the talk and the activities in which the students participated in "an attempt to provide them with the science content, facts they needed to progress." Hubbard explained the change in the class discussion dynamic as, "I had achieved my goal, they now had the science to progress and could have a generative discussion."

The consensus discussions explanations are framed around content knowledge and student experiences. The pedagogy talk began very dialogically because both Hubbard and her students were comfortable with the content. Hubbard, regardless of which perspective is addressed, she knows little or a lot about portfolios, was comfortable with her level of understanding. The students are accustomed to assessing student work and were comfortable discussing this pedagogical content. The talk shifted to more monologic character when the students had to apply their roles as teachers and their content knowledge to a new scenario, determining other necessary components for the portfolio. They had little or no experiences doing so, and thus the discussion changed character. The monologic quality of the science talk resulted from Hubbard's determination that the students could not move on without being provided more science content with which to work. Once she felt they had this content knowledge she allowed for dialogic discourse.

Demonstrations

The demonstration examples chosen for analysis included a pedagogical technique, interviewing students, and a science demonstration about atmospheric pressure. As would be expected in a demonstration, these two episodes both emphasized the teacher's voice over that of the students. Accordingly, the demonstrations themselves were highly monologic in nature (Newman et al., 2001a) and readily addressed Hubbard's goal of demonstrating how teachers could use each type of demonstration. After the pedagogy demonstration, Hubbard did not provide an opportunity for the students to discuss what they witnessed nor did she even ask them to evaluate what had occurred. She moved on to the next topic without any assessment of their experience. In contrast, immediately after the science demonstration, she gave the students the chance to talk in their small groups about what happened and why. Moreover, after the small group discussion, the students shared their ideas as a class. However, examination of the discourse following both demonstrations indicates that the students' intents did not align with the instructor's (Newman et al. 2001b).

Following the interview demonstration, Hubbard intended for the class to evaluate the interview of the student using articles they had read. However, the students became more concerned with how they would conduct their interviews of elementary students later in the week. Instead of looking at the articles and evaluating the interview process, the students reread their assignment and tried to understand the criteria for the project.

The science demonstration initially included no student voices. During the introduction Hubbard lit a candle in a pan of water and covered it with a glass. While science demonstrations are often QAE, Hubbard did not even seek the students' predictions prior to or ideas during the demonstration. While we readily identified the science demonstration, like the pedagogy demonstration, as monologic (Newman, et al., 2001a), it became difficult to classify the science demonstration as science or pedagogy after learning the instructor's intent. Hubbard identified her goals for the science demonstration as pedagogical, wanting her students to examine how the demonstration could be used for assessment. Even though she stated her goal, the students did not acknowledge her pedagogical intent in their discussions and instead focused on trying to make sense of the science (Newman et al., 2001b).

When trying to explain the discourse during the interview demonstration, Hubbard focused on the competition between her educational intent and the students' sense of urgency about an upcoming assignment.

> The interview demo was so interesting because I saw myself get sucked into their intent, but I was fighting all the way on the inside. This made it so that there really wasn't dialogue, and we went to their intent, finding out directions and how it would be graded. My intention of discussing the purpose and pedagogy never even came to light on the video…in fact, everyone else in the world just has to trust that was my intent based on my word because there is NO evidence of that! (Except my frustration!). I know they didn't learn as much as they could have that day. Time constraints became the issue during this class. I wanted to provide the students with the last segment of class time to work on their interview protocols since some of the students would be conducting interviews the next day. I couldn't get them to examine the interview, so I knew I just had to make my point and move on.

As with the pedagogy talk, the monologic nature of the pedagogy demonstration is rooted in the time constraints that arose from differing intents.

The issue of differing intents also guided the science demonstration discourse, but with inversed results. Hubbard explained how her example of an alternative assessment strategy became a science talk.

> The science assessment demonstration is a great example of how their lack of science content kills my plans. WOW! I had hoped that we could use the demo to discuss alternative assessment—I even stated this goal in response to an expressed need for this, but like I said, it really doesn't matter to them! Then away we went! They had no idea what was going on scientifically, and I was so struck by their dialogic discussion that I let go! I think this doesn't follow my "rule" of becoming monologic [when intents differ] because I didn't fight it! They were quite capable and used to dialogue at this point in the class, and I let them go with their intent. I gave in without even considering trying to take over again. And I don't regret it! What an amazing discussion…although I will say that the "old fashioned" science teacher in me did try to interrupt and at least say "I DON'T THINK SO!!!" But by that time they had me so bamboozled that I'm not sure I could have explained it to anyone either!

Hubbard used the differing intents of her and her students, grounded in the students' lack of understanding the science content, to explain the monologic nature of this demonstration. The students complete lack of understanding of the scientific principles involved in the demonstration dominated the discourse and their exposure to previous science talks led them to conduct one of their own.

When comparing the two demonstrations, Hubbard focused on the extremely different discourse that occurred out of the same educational issue, teacher and students having differing intents.

> I think it is interesting to contrast these two situations because in one I fought it and it still went their way, but was much less productive. In the other, they won and it still was a productive class. By the same token, I'm not advocating just letting it go wherever they take you every minute, but perhaps I need to consider each situation more carefully before trying to regain "control."

In this comparison, Hubbard expressed her bias towards dialogic discourse being more productive and leading to better student understanding. Further comparison of the demonstrations revealed the reoccurrence of time constraints, student content knowledge, and student experiences as issues influencing discourse. Because she had other plans for the remainder of the class, time became an issue during the pedagogy demonstration. Hubbard was unwilling to let an unplanned dialogic discourse occur and interfere with the remainder of her lesson. In contrast, she readily surrendered the classroom plans for a science based dialogic discussion. She defends this with her amazement at the students' lack of science understanding and their need for the experience. She also refers to the students' lack of experiences with alternative assessment.

Discussion

Following participant speaking patterns during discourse analysis allowed us to initially frame and distinguish the differences between science and pedagogy instruction. Knowing the function of the utterances also became necessary to understand the nature of the speaker's voice. Yet, defining which utterances were teacher voice and which were student voice required knowing more than by whom and when the statements were made. The role and intent of the teacher and students as they spoke also required examination. The complexity increased as the perspective of the researcher, observer or participant, resulted in disagreements about the data and analyses.

The instructor accounted for discourse differences in three major ways: (a) time constraints, (b) content knowledge, and (c) students' experiences. Monologic discourse occurred most often when the instructor felt pressed for time, had a "low comfort level with the material," or determined the students did not have a basis for participating in dialogic discourse. She used the first two conditions to explain monologic discourse during both science and pedagogy instruction. However, she used the rationale of student experience only to account for monologic discourse during pedagogy instruction.

Time Constraints

Inadequate time for instruction occurred when the instructor's and students' intents did not align. While discussions based around misaligned intents often started dialogically, the discourse increased in monologic character as Hubbard tried to redirect the class towards her intents, often by resorting to a recitation strategy.

> My perception of a time constraint is often framed in my desire to get the class back on an even keel. Such as when the class intents differ from my own or I feel the class needs something, some piece of knowledge, to move on. Thus, I feel this sense of urgency to do 'it' now even if there is an hour left. Cheap closure.

The issue of perception when discussing time constraints further complicates the issue. Hubbard's statement illustrates that a "perception" of a time constraint may occur when there actually is plenty of class time remaining for the content at hand.

Monologic discourse resulting from time constraints occurred more frequently for pedagogy than for science. During the science demonstration, Hubbard "didn't fight the students" desire for a science content discussion even though that was not her stated purpose for the demonstration. Yet during the pedagogy demonstration and the pedagogy talk, Hubbard "battled the students to regain control" and ended their dialogic discourse by engaging in recitation. Hubbard explained this difference with her greater comfort level with science teaching than pedagogy teaching. This issue is discussed further in the content knowledge section.

In a post-class interview, Hubbard expressed her disdain for using time as an excuse, "Time is the issue, but I am tired of that as a reason. There must be more to it than time." Identifying the differing intents of Hubbard and her students helped her come to terms with this issue. She began to understand that time constraints are often the results of other issues and not simply restricting entities in and of themselves. Initially, Hubbard felt that because dialogic discourse required more class time than monologic discourse, it was often the root of her time issues. However, perceived time constraints arose from the interconnectedness of intents, comfort levels, class time, and the characteristics of discourse. Thus, it is difficult to ascertain which causes which due to the intertwined nature of all components.

Content Knowledge

Because she has had more preparation, both formal and informal, on how to teach science dialogically, Hubbard expressed "a greater comfort level with the material when teaching science" as opposed to pedagogy. Her experience teaching science at the middle school level also added to her greater comfort with science content. Additionally, she stated that for her, pedagogy is more "tacit knowledge" than science content. She was much more aware on an explicit level of how to teach science than how to teach the teaching of science. Accordingly, she tended to teach science more dialogically than pedagogy, allowing the students to explore their ideas when they "were in [her] comfort zone."

During several lessons, Hubbard felt the pedagogy she was trying to teach was restricted by the students' lack of science content knowledge; yet, she never expressed a concern that this issue restricted teaching science. Regardless, she stated that she finds this idea that lack of science content knowledge could interfere with pedagogy distasteful.

> I was and still am uncomfortable even saying that I believe that students have to have content knowledge before they can discuss pedagogy. I felt like this was a statement that is true in some circumstances and not in others. Once again, my fear that I don't know what I am talking about arose because I feared that others would say "that's ridiculous." Not to mention that I have made similar claims to my students when they insist that they must front-load their lessons with content "introductions" so that their students will know how to carry out and interpret the investigation. To me that is ludicrous; it is simply telling the students all the answers. But now I heard myself making a similar excuse.

In a science methods course, science and pedagogy are often so intertwined, it is impossible to teach one and ignore the other. Thus, when teaching the pedagogy of science demonstrations, the science content involved can readily become the focus of the discussion. Analogously, when teaching science content, pedagogy issues such as classroom management can become the focus for the students. The balance between pedagogy and science is difficult for an instructor to set and maintain, and for researchers to determine.

Students' Experiences

Hubbard felt the students' lack of teaching experience greatly reduced her use of dialogic discourse during pedagogy instruction. Few of her students had science teaching experience and tended to bring only their experiences as students to pedagogy discussions. She felt the students' limited experience teaching restricted their abilities to participate actively in classroom discussions about pedagogy. Thus, she felt monologic discourse could be useful in the education of preservice teachers when the students lack the knowledge or experience to participate actively in dialogic discourse. Hubbard did state that she saw a slight increase in their desire and ability to participate in pedagogy discussions after the field component of the methods course.

Conclusions

The function of the discourse, generative versus authoritative, initiated by the instructor is linked to its nature, dialogic versus monologic. When the instructor wanted to convey meaning, discourse was authoritative and monologic. She often attributed this form of discourse to time constraints and/or lack of students' content knowledge with that particular topic. When she wanted students to inquire, discourse was generative and dialogic. The instructor attributed this discourse form to greater student content knowledge and more teaching experiences with the topics being taught. Another explanation for discourse differences, not identified by the instructor, might lie in the teacher's educational goals and plans.

Differing intents influenced the nature of the classroom discourse and the role that time constraints played with regard to discourse. The student's intents differed from the teacher's intents when she challenged the students to examine an issue from the perspective of a teacher. The student's inability to get beyond the student perspective precluded the teacher's goals from being achieved, regardless of her planned discourse strategy. Because the methods students never observe the instructor teaching children and the instructor can only observe the students teaching children for very brief periods of time, methods instructors are very limited in their ability to help their students in the role of teacher. Thus, our students will struggle to be effective science teachers until they gain experience teaching science and are able and willing to reflect from the teacher perspective.

Implications and Relevance to Science Teacher Education

Understanding what happens in a science methods course is an important step in creating a successful teacher education program. We have established that differences occur in discourse in our science methods course based on the content being taught. The instructor was less likely to teach dialogically during pedagogy segments than during the science segments of the lessons. Moreover, perceived time constraints, student content knowledge, and student teaching experiences also determined discourse form. Current learning theory, including distributed cognition, informs educators of the importance of dialogic discourse in the classroom (Brown, Collins, and Duguid, 1991; Salomon, 1996), as do national science education documents (AAAS, 1993; NRC, 1996, 2000). Moreover, educational goals, learning environments, and teacher roles have changed dramatically in recent years and have influenced educators' views of effective classroom discourse (Bransford, Brown, & Cocking, 1999). Understanding why discourse differences occur in science methods classrooms is important if preservice teacher educators are to improve their programs and promote inquiry in science classes. In addition to establishing why the differences occur, our research can lead to other important research projects such as determining if the students are aware of the differences in discourse and if the differences affect student achievement.

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STRATEGIES ENABLING TEACHERS TO CRITICALLY ANALYZE LEARNING AND TEACHING

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This paper shares the findings from four years of Eisenhower funded research which identified conceptual obstacles and enabling strategies for interdisciplinary teams of grade 4-12 teachers to develop and implement integrated standards-based science and mathematics teaching and assessment plans in their classes that are effective in helping students learn. The program provided professional development for 80 teachers in 37 teams of science and mathematics teachers in 12 rural and urban school districts to develop and implement integrated teaching and assessment plans that follow the *National Science Education Standards* (National Research Council, 1996), *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000), *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), and *Standards of Learning for Virginia Public Schools* (Board of Education Commonwealth of Virginia, 1995). Though the research investigated teaching and assessment, this paper focuses on strategies to enhance the teachers' critical analysis skills for assessing student learning.

As teachers change the way they teach to meet new national and state standards, they need to also change the way they plan for teaching and assessment of student understanding. The purpose of this research was to identify conceptual factors that limit teachers' ability to successfully develop and implement effective teaching and assessment plans for their students. Once limiting factors were identified, enabling strategies were developed. The main areas for teacher professional development during the summer and implementation year were standards-based integrated science and mathematics subject matter and pedagogy, planning for teaching and assessment, and critically analyzing student learning (Scantlebury, Boone, Kahle, & Fraser, 2001). Though the science theme varied from year to year, an underlying focus on data analysis and experimental design remained. This presentation will focus on the support scaffolding that enabled teachers to more effectively critique their students' learning.

This study has implications for K-12 teacher professional development as we seek to help individual teachers and teams of teachers plan for standards-based teaching and assessment. As obstacles are identified and enabling strategies developed, teachers will be better able to plan and teach in ways called for in the state and national standards for science and mathematics.

Theoretical Underpinnings

The study grew out of the recognition of the increasing importance for universities and schools to work together to support the learning and teaching of science and mathematics. It also grew out of the need to help teachers develop a vision of the kind of teaching and assessment called for in the national standards and the need to implement this type of learning and assessment in their classes (Anderson & Helms, 2001; Kahle, Meece, & Scantlebury, 2000; Lynch, 1997; Sterling, 1997, 2000, 2001; Sterling, Olkin, Calinger, Howe, & Bell, 1999).

Since few changes usually take place as a result of professional teacher development (Guskey, 1995), we built into the program characteristics of "best practices" and “best of the best” for exemplary teacher professional development programs including a thematic design, supportive infrastructure, and utilization of evaluation (Ruskus, Luczak, & SRI International, 1995). A systemic approach was used that aligned curriculum, instruction, and assessment with local, state, or national standards and recruited teams of teachers from the same school and school division with the support of that division (Scantlebury et al., 2001). Additionally we focused on collaboration and follow-up (Gallagher, 1996; Ruskus, et al., 1995). Research suggests that meaningful collaboration facilitates educational reform (Anderson & Helms, 2001; Fullan, 1991; Keys & Bryan, 2001) and collaborative work cultures enhance student learning (Crawford, Kelly, & Brown, 2000; Newmann & Wehlege, 1995).

To enhance the daily professional development environment of the summer workshops, many aspects of collaboration were built into the program (Keys & Bryan, 2001; Sweeney, Bula, & Cornett, 2001; Van Driel, Beijaard, & Verloop, 2001). Social learning theory suggests the importance of observing and modeling behaviors, attitudes, and emotional reactions of others as part of self-efficacy (Bandura, 1977). Therefore staff members were carefully chosen and provided with their own professional development training so that they became a team immersed in the projects culture. Vygotsky’s (1986) social development theory suggests that social interaction plays a pivotal role in cognitive development with peer collaboration exceeding what can be learned alone. Team problem solving and planning were an integral part of the program. According to Bruner (1960, 1990), learning is an active process where the learner constructs new knowledge by discovering principles themselves under the guidance of an instructor. Therefore instruction encouraged active dialog to uncover the structure and organization of new information in order for the learner to go beyond the information given (van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). Experiential learning situations were established through classroom experiences where the learners became personally involved in self-initiated activities when they designed and conducted their own research investigations (Rogers, 1969). Cross (1981) emphasizes the importance for adult learning to be self-directed and problem-centered where they have as much choice as possible. Teacher teams were given the flexibility to adapt all assignments and research to their own schools and working situations. The perception of self-efficacy enhances cognitive development (Bandura, 1993, 1997).

Initially the study focused on the scaffolding teachers needed to plan and teach standard-based science and mathematics. During this time, we realized that until teachers focused more on assessing student understanding few gains were likely to be made (Brown & Shavelson, 1996; Champagne, Lovitts, & Calinger, 1990; Kyle, 1997). While focusing on assessment, we realized that many teachers needed to be more critical about their students' learning and their teaching. Our study has now been extended to focus on enhancing the teacher's ability to critically evaluate learning and teaching.

The immediate impetus for focusing on critical analysis of learning and teaching by teachers occurred when a team of teachers, who were reporting on a hands-on lesson where learning was not likely to have taken place, justified the success of their lesson by claiming their students had fun. Though fun is a desirable outcome from learning, it is not a replacement for learning. This particular team of teacher did not seen to have the knowledge and skills to critically analyze success in the classroom. Though many teachers are naturally reflective and critical about student learning, many are not. It became our goal to help all teachers critically analyze learning and teaching for the purpose of continually enhancing learning.

Design and Procedure

Program Design

Structurally the program was set up to include teams of teachers collaboratively studying over an extended time period (Kahle, Meece, & Scantlebury, 2000; U.S. Department of Education, 1999; Van Driel et al., 2001). The program had an initial concentration of study and planning time for teachers in the summer followed by six to nine months of implementation, analysis, and sharing of findings during the academic year (Anderson & Helms, 2001).

The program was designed to provide participating teachers with professional development necessary to enable them to develop and implement integrated, hands-on, inquiry-based science and mathematics teaching and assessment plans (Parke & Coble, 2001). During the summer workshops the teacher teams focused on developing integrated teaching plans that included the basic elements of experimental design and data analysis (Cothron, Giese, & Rezba, 2000; Virginia Department of Education, 2001). During the academic year the teachers focused on implementing their plans and assessing their students growing understanding with support from their team members, other teams, and the instructional leadership team (Anderson & Helms, 2001; Sweeney et al., 2001; Van Driel et al., 2001).

Leadership Team

The first phase of the program was to develop a leadership team that co-planned and taught the summer workshops and follow-up sessions. The team consisted of university faculty from science, mathematics, and education and teacher leaders from the different participating school divisions who were specialists in science or mathematics. Leadership skills were developed through increased knowledge of integrated science and mathematics gained by working with an interdisciplinary team during the planning and piloting process, critical analysis of student-centered teaching strategies and assessment practices, development and implementation of workshop plans, peer teaching and mentoring, and reflection and evaluation on every aspect of the program.

Teacher Teams

For this project, the ideal team was 2-3 teachers from the same school teaching the same grade level who could plan together. When this was not possible, teachers were allowed to choose to work with teachers from different schools but all at the same grade level or with teachers from different grade levels at the same school. Though we were not assessing effectiveness of team configuration, all arrangements appeared to enhance teachers' experiences. Teacher connectivity and camaraderie appeared to be more significant than team configuration. The teacher teams created teaching plans that incorporated multiple forms of diagnostic, formative, and summative assessment to monitor student learning in their classes (Bell & Cowie, 2001; Treagust, Jacobowitz, Gallagher, & Parker, 2001). The research task for teachers was to identify a content standard and prove to their peers through assessment of understanding that their students had mastered the standard. If the standard was not mastered, they were to identify their students' misunderstandings or misconceptions and their plans for enhancing understanding.

Research Methodology

Using a constant comparative process (Glaser, 1978; McMillan & Schumacher, 1984), data collected through surveys, interviews, focus groups, observations, and analysis of artifacts identified obstacles the teacher teams needed to overcome in developing integrated, inquiry-based science and mathematics teaching and assessment plans. A leadership team of scientists, mathematicians, and educators conducted the on-going formative research. The team analyzed the data on a daily basis during the summer program. This staffing arrangement provided triangulation among the staff observations and interviews where staff members independently identified problems that were in most cases observed by others.

Through a continuous improvement model, support scaffolding was developed that enabled teachers to effectively conduct research on their students understanding (National Commission on Mathematics and Science Teaching for the 21st Century, 2000). The support scaffolding provided teachers with a simple way to assist in interpreting the complexity of teaching and constructing plans and hence assisted in the change process (Anderson and Helms, 2001; Barnett & Hodson, 2001).

Findings

Scaffolding for Planning

The scaffolding that enables teachers to develop a vision of the kind of inquiry-based teaching and assessment called for by the standards and to effectively plan to create this type of teaching in their classroom fell into two categories - conceptual organizers and guided planning. Conceptual organizers in the form of graphic organizers proved to be especially helpful and were created to guide planning for teaching, assessment, and critical analysis.

Obstacles and Enabling Strategies for Teaching and Assessment

It became apparent that when teachers were developing their own teaching plans that were not based around a core set of materials such as a textbook, they were left with an organizing structural void. To fill this void, an inquiry-based conceptual organizer, a type of advanced organizer, provided an organizing structure/scaffolding around which to base teaching plans (Sterling, 2000). The inquiry hierarchy provided structure to both subject matter and pedagogical strategies. The inquiry hierarchy is similar to backmapping used to develop *Benchmarks for Science Literacy* (AAAS, 1993) in that it shows the relationship of unit science concepts. It is also similar to a problem-based unit that has a question guiding the instruction.

Likewise it was found that teachers also needed an organizational structure around which to develop their assessment plans. The assessment timeline conceptually organized a process for teachers to identify and monitor student learning (Sterling, 2001). By developing a before, during, and after paradigm of diagnostic, formative, and summative assessment, the teachers were able to embed assessment in their teaching. The teachers found that when they embedded assessment routinely as part of their instruction, they became more effective at assessing their students understanding of science and in turn informing their instruction (Treagust et al., 2001).

Beyond the conceptual organizers, guided planning provided additional structure for the teachers that enabled them to create teaching and assessment plans which they could conceptually defend to their peers. The guided planning was a sequential series of decisions made by the teachers about the teaching plan or assessment plan they were developing, followed by an analysis of their decisions made from different perspectives.

Obstacles and Enabling Strategies for Student Understanding

While most teachers easily focused on assessing student understanding, peripherally related issues such as fun and active student involvement sidetracked some. Both fun and active student involvement are desirable outcomes. However, they may not be directly related to developing student conceptual understanding.

To help teachers critically evaluate learning, a critical analysis taxonomy was developed showing a hierarchy of levels for analysis and evaluation (Figure 1). The taxonomy provides a structure for the purpose of continuous improvement for the teachers to evaluate effective learning and teaching. The taxonomy progresses from analyzing the effective aspects, to identifying the weaknesses, to suggestions for improvement, to extensions or links to other information. Using the taxonomy provided teachers with a conceptual framework for the evaluation process that delved at successively deeper levels of evaluation.

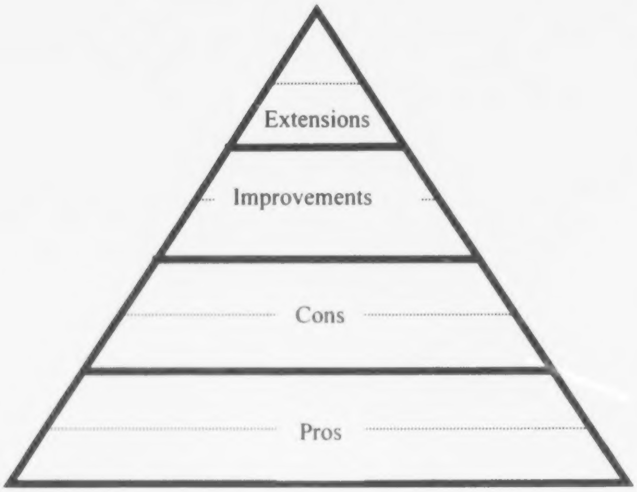

Figure 1. Critical analysis taxonomy.

The critical analysis taxonomy also guided the teachers analysis when they implemented their teaching and assessment plans. By having teachers share all the levels of the critical analysis hierarchy, they celebrated their successes and group problem solved areas that needed further development. They became a team of professionals working together.

Critical Analysis Taxonomy

The critical analysis taxonomy provided a mental model for teachers to analyze student understanding. The taxonomy, a graphic organizer, combined the elements of a hierarchy with the need for depth of multiple formats of analysis. The reason for the hierarchy aspect was because the multiple levels for evaluation are based on a continuous improvement model and the research of Bloom (1956) and others that classifies thinking in a six level cognitive hierarchy from low to high level and that shows that people understand at many different levels. The hierarchy is also based on motivation systems theory and the need for positive regard for success (Ford, 1992). Continuous improvement is the goal but acknowledging what is working well is important so that it continues to be repeated. The continuous improvement model has the focus on improvement and not change for change sake. Therefore, it is important to include what is working so that it is not changed but continued.

The critical analysis taxonomy provides a basis for evaluating most things and can be used by teachers as well as students. It could apply to a lesson being taught by a teacher or to evaluating an essay or poster by students. For a continuous improvement model the hierarchy builds from compliments, to criticism, to suggestions for

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improvement, to extensions. Therefore it could be viewed as a cycle or spiral with each round of analysis informing the teacher and student about the level of understanding or lack of understanding. This in turn would inform instruction and learning, and focus on improvement.

All levels of the hierarchy can be subdivided into two groups, critical analysis/comments that are peripherally related or that focus on core elements of effectiveness for the work being evaluated. Comments that are central to the effectiveness of the work being evaluated are the target for each level. However, by including peripherally related comments, a focus can be placed on honing in on core elements, but also acknowledging peripherally related comments and analysis.

Pros

The base of the hierarchy is identifying positive or successful aspects of the work being evaluated. Most people find it easier to give compliments than to criticize. An example of the two levels within the pros category when evaluating a teaching activity are comments about peripheral issues such as students having fun as compared to comments about student learning. Though having fun is desirable, it is not usually the central purpose for an activity.

Cons

Identifying aspects that are not working or are only partially working is the next step and a prerequisite to improving. It is generally more difficult for people to be forthcoming when analyzing what is not working than what is working because of values associated with lack of success. Therefore we deepened the "cons" part of the analysis to a problem-solving/data analysis paradigm where problems are solved (Cothron, Giese, & Rezba, 2000; Gabel, 2002) (see Figure 2). Analysis of errors of understanding is a cyclic process that starts with identifying errors and looking for patterns among identified errors. Analyzing reasons for errors and clarifying as needed by gathering more data about what led to errors enables teachers or students to plan for remediation. After remediation, the cycle starts again with identifying evidence of understanding or errors in understanding to determine if remediation has been successful.

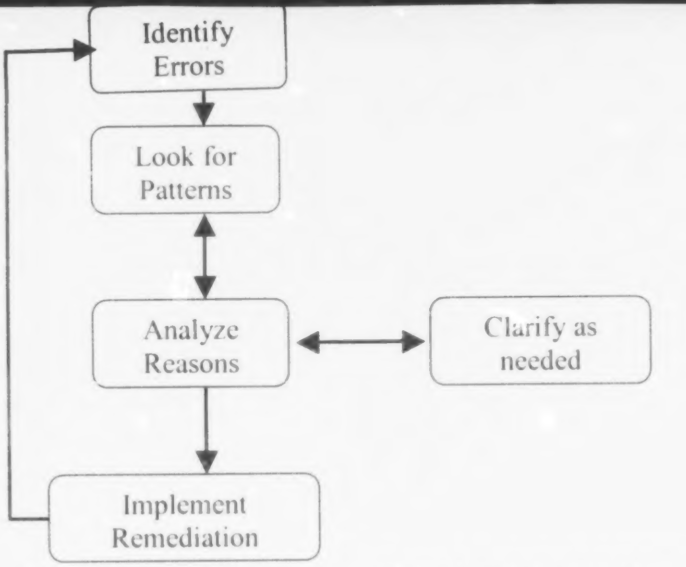

Figure 2. Error analysis.

Establishing a safe and supportive environment that focuses on continuous improvement and rewards honest reflection is crucial to encourage sharing especially of less than stellar performance by students or teachers. As part of the sharing process, teachers shared samples of student work. In most cases they shared three samples, one each from the top, middle, and bottom third of their class. Inquiring into your own practice and sharing about research findings and dilemmas is part of the new inquiry group paradigm for professional development (National Commission on Mathematics and Science Teaching for the 21st Century, 2000).

Improvements

After identifying what is not working, suggesting possible solutions to problems or ways to make something more effective is the next level.

Extensions

Extensions are ways that the work being assessed can be connected or extended to make it more meaningful. It tends to be value neutral and thus brings the focus back to quality teaching and assessment at all levels.

The taxonomy proved to be most helpful in stretching teachers to go beyond accepting the status quo to improving learning and teaching. The teachers also found that the taxonomy could be used with students to help them with evaluation of their own and other students' work.

Conclusion

This study identified conceptual obstacles for standards-based teaching and assessment and developed support scaffolding that enabled teachers to understand and accommodate into their teaching style a student-centered approach to assessment. The scaffolding included an assessment timeline and critical analysis taxonomy that

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conceptually organized the assessment process and a series of assessment analyses that focused on the effectiveness of learning and assessment strategies.

By conducting research on their own students' understanding, the teachers appear to critically analyze the teaching and learning process. The teachers found that when they embedded assessment routinely as part of their instruction, they became more effective at assessing their students understanding of science during the teaching process especially when they used multiple forms of assessment.

As new ways of teaching and assessing learning challenge traditional methodology, teachers need time to work through the conceptual change process. As the teachers are introduced to new methodologies and develop a new understanding of effective science teaching, they require multiple experiences that challenge their understanding of learning. A simple conceptual paradigm and a series of experiences that assists the teachers in investigating overtime the new strategies at ever increasing depths helps teachers to progress through the change process.

By using the critical analysis taxonomy and conducting research on their own students understanding, most teachers appear to be able to critically analyze the teaching and learning process for their students. Our research identified conceptual obstacles for creating and evaluating standards-based teaching and assessment and developed scaffolding that enabled teachers to understand and accommodate into their teaching style a student-centered approach to hands-on, inquiry-based teaching and assessment that led to assessing and extending student conceptual understanding.

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A QUANTITATIVE COMPARISON OF INSTRUCTION FORMAT OF UNDERGRADUATE INTRODUCTORY LEVEL CONTENT BIOLOGY COURSES: TRADITIONAL LECTURE APPROACH VS. INQUIRY BASED FOR EDUCATION MAJORS

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The discrepancy between how most students experience introductory science courses at the university level and how the National Science Education Standards (NSES) recommend they should be experienced seems vast (National Research Council, 1996). Halls are filled with a hundred or more students listening to lectures. Smaller groups participate in prescriptive labs that seldom relate learning to the daily life of the student. The experience that the majority of students have after such a course is that of listening to many hours of lecture, reading, and memorizing material from a text. These courses are generally designed for the non-science major; those who will be future writers, social workers, and artists. However, these courses are also where most of the future elementary educators in this country will learn the science concepts they will be expected to teach in their own classrooms.

The NSES (1996) recommend that prospective educators experience science in situations that include problem solving, inquiry, and the use of hands on experiences in order to develop a "broad base of knowledge" that will allow them to understand the role, processes, and nature of scientific inquiry (p. 59). They must also understand the basic facts and principles of the sciences and be able to make connections between and within them (NRC, 1996). Looking at just these few guidelines among those recommended, it is difficult to believe that elementary education majors are receiving the education suggested in the standards through participation in the traditional lecture and laboratory format classes. The recent publication of the report *Science Teacher Preparation in an Era of Standards Reform* recommends that universities and their faculty develop courses for elementary education students that reflect the best practices recommended by the NSES (National Research Council, 1997). Such courses should include pedagogy and assessment practices, as well as the content knowledge that will be needed in their future profession. Classes should be designed so that the subject matter being taught in the college classroom reflects the subjects that the students will eventually teach in their own classrooms.

Professors of physics or biology would not be expected to be experts on the newest and most effective teaching practices in elementary education (K-8), nor would one who specializes in education be expected to be expert at all of the disciplines of science. Therefore, education and science professors need to work together to create experiences that integrate content and pedagogy (Stevens & Wenner, 1996; NRC, 1997). Several science courses for education majors have been created around the country through collaborative efforts between departments and colleges with positive results. Specialized chemistry classes have been created at Colorado State University and at the University of Maryland (O'Haver, 1997; Jones et al. 1997). Research gathered from a physics class for education majors at Pennsylvania State University found by integrating content taught in a hands on manner with pedagogical practices in a comfortable classroom setting that students confidence and learning were enhanced (McLoughlin & Dana, 1999). Biology courses for education majors at the University of Nebraska and St. Clouds have promoted positive changes in attitude toward science and in the confidence the students in seeing themselves as science teachers (Hall, 1992; Friedrichsen, 2001).

In situations where it was impossible to create courses specifically for education majors changing the manner in which students participate in the traditional lecture and lab have also shown positive results. At Clemson University, a program had been previously introduced that provided education majors with experiences that followed NSES recommendations embedded in a format of lecture and lab. Recent research by Fones et al. (1999) found that by reducing the amount of time students had between when the discovery phase (the lecture) and the concept development and application phases (the lab) took place, through integration in an experimental course, student attitudes toward the subject and the teaching of it were more positive. Stallheim-Smith and Scharmann (1994) found that by creating a recitation section specifically for education majors where their "learning styles and interest orientations" were considered significant differences were found in the achievement when compared to other sections during that semester and when compared to the cumulative data from the previous ten years (p. 170).

Recent literature exists that demonstrates that the establishment of science courses for elementary education majors proves to have positive effects, however, the controversy of "specialized" sections or courses still exists. It is important to acknowledge that the most of the recent literature research has been on the students' attitudes or comfort levels with the subject. The question remains whether students who take courses such as these learn the content that is necessary to become educators who can create experiences in their classrooms that conform to the recommendations of the NSES (1996). If colleges and universities are going to be convinced that designing such courses, which require more money and faculty resources to develop and teach, rather than keeping what is currently being taught, evidence must be shown that the students who participate in them are learning more than a positive attitude.

Purpose

The purpose of this study is to determine if there were any statistically significant differences in the pretest and posttest examination scores between students in two undergraduate biology classes taught in two fundamentally different praxes at the University of Nevada, Reno (UNR). Biology 100, an introductory biology course for non-majors, is taught in a traditional lecture and laboratory format. Biology 110 was a newly created course designed for elementary education majors using an approach recommended by the NSES (1996). This approach includes inquiry, collaborative work, and investigations. Data analyses should reflect any differences in students understanding of biological content presented in each course, based upon final examination scores.

From this research, new information regarding the relationship between how a course is taught and the understanding of course content by the students may be gained. This may effect how college-level science courses are designed, independent of students' academic majors. If it can be demonstrated that students who participated in the Biology 110 course, *Biology for Education Majors*, outscored their peers in the traditional Biology 100 course, *Principles and Applications of Biology*, than the methods of teaching used in the Biology 110 course could be advocated for other science content courses at the college-level.

Background

The University of Nevada, Reno (UNR) offers two lecture sections of Biology 100, which are composed of between 150 - 200 students per section and 15 lab sections where the students are divided evenly, usually about 20 students per lab section. Biology 100 is a survey course offered in general content biology for all non science majors. It is a Core A science requirement (Core A meaning that it is a core science with a minimum lab hour requirement in addition to a pre-requisite in college algebra and a writing requirement). Biology 100 meets for lecture two times per week and has a requirement of a three hour lab that must be attended four times during the semester. UNR also offers Biology 190 for science majors (which was not considered in this study).

Biology 110 was originally developed and taught in the spring semester of 2001. The course was initially funded by a Howard Hughes Medical Institute (HHMI) Grant to the University of Nevada, Reno. The portion of the grant funding this initiative is part of the undergraduate / graduate portion of the grant for content enhancement for teachers and pre-service teachers. Biology 110 was offered as a general biology course for elementary (K-8) education majors. The course consisted of a weekly four hour lab and an additional 1 hour recitation, which meet two days after the lab. The course was taught as a collaboration between the College of Arts and Science (Biology Department) and the College of Education (Curriculum and Instruction Department) Dr. Alan Gubanich co-taught the course from the Biology Department and Dr. David Crowther co-taught the course from the College of Education. The lab was designed using a hands-on inquiry approach to teaching content biology. Biology concepts covered in the lab were comparable to the topics and concepts in Biology 100 and included a range of Environmental concepts, Biogeochemical Cycles, Classification, Adaptation, Evolution, The Cell and Cell Division (Mitosis), Meiosis, Human Reproduction (including STD's), Mendelian Genetics, Molecular Genetics, Protein synthesis, Cellular Respiration, Photosynthesis, and Body Systems and Health. The lab topics were taught modeling current education methodology and pedagogy, utilizing a constructivist philosophy and an inquiry mode of presentation. The one hour recitation, which was offered two days after the lab, allowed for the students to make sense of the content explored in the hands-on setting and allowed for discussion of the text which was assigned to be read (most often) after the lab experience.

Biology 110 was open to 25 - 30 elementary (K-8) education / pre-education majors, although only 15 enrolled in the course. This small number was to be more comparative to a lab section rather than a lecture section. Biology 110 is currently under institutional review as a Core A science.

Hypotheses

Hypothesis 1: There will not be a statistically significant difference between the pretest and posttest mean scores of those who participated in Biology 110, *Biology for Education Majors*, during the spring semester of 2001.

Hypothesis 2: There will not be a statistically significant difference between the pretest and posttest mean scores of elementary education majors who participated in Biology 100, Principles and Applications, during the spring semester of 2001.

Hypothesis 3: There will not be a statistically significant difference between the pretest and posttest mean scores of all students who participated in Biology 100, Principles and Applications, during the spring semester of 2001.

Hypotheses 4: There will not be a statistically significant difference between the post test mean scores of those who participated in Biology 110, *Biology for Education*

Majors, and the elementary education majors who participated in Biology 100, Principles and Applications, during the spring semester of 2001.

Hypothesis 5: There will not be a statistically significant difference between the post test mean scores of those who participated in Biology 110, *Biology for Education Majors*, and all students who Participated in Biology 100, Principles and Applications, during the spring semester of 2001.

Review of the Literature

The recent publication of the Third International Mathematics and Science Survey (TIMSS) (1999) reported that the trend in science achievement in the United States was slightly below that of the international average, though there was an insignificant gain between the scores from 1995 to 1999 (p. 36). Results from the United States Department of Education showed that the average science scores between 1996 and 2000 remained the same for students in grades four and eight, but dropped significantly in grade twelve (United States Department of Education 2001). When considering the ultimate goal of a scientifically literate society, and comparing that goal to the outcome of these recent studies and publications such as "Before It's Too Late," (National Commission on Mathematics and Science Teaching for the 21st Century, 2000) it appears that not enough is being done to change the experiences students have while learning science.

The National Science Education Standards' (NSES) (NRC, 1996) call for a "reform effort in science education [that] requires a substantive change in how science is taught" (p. 56) is not surprising. The NSES recommend that students at all levels, as well as "prospective and practicing teachers of science, must take science courses in which they learn science through inquiry, having the same opportunities as their students will to develop understanding" (p. 61). The learning that takes place in a classroom is dependent upon the effectiveness and attitude of the teacher in that classroom toward the subject being taught.

There is a relationship between the experiences preservice teachers have during their elementary and secondary education and how comfortable they feel learning the subject later. Research has shown that preservice teachers who learned science during elementary and secondary schools in an atmosphere that encouraged questions and provided hands-on experiences were more likely to feel positively toward the subject and were more comfortable while learning science as college students (Mulholland & Wallace, 1996; Moore & Watson 1999). A positive correlation has been shown to exist between an elementary education major's previous experience in school and with informal science activities and his or her confidence while teaching science. Indeed, Jarrett (1999) found that "the best predictor for interest in science was a positive experience in elementary school" (p. 53). Watters and Ginns (1997) found that when elementary education majors were in the position to learn subject content, but were not comfortable with the subject, "high levels of anxiety are generated leading to an expressed desire to avoid the teaching of these subjects in their future career" (p.13). Tingle (2000) found that many practicing teachers who did not have the opportunity to learn science in a manner recommended by the NSES were "intimidated by activities in the classroom…because activities made students ask questions, and the teachers often did not have the answers" (p. 42). As students of all ages learn science they need to experience it in a hands on, inquiry manner, thus increasing their comfort with the subject and the likelihood that they will take more science courses through their education. A number of these students will go on to become the teachers who will be able to create such an atmosphere in their own classrooms.

Many elementary education students, however, come to universities with low levels of comfort and interest in science. In an attempt to create experiences that conform to the NSES many universities have created science courses that teach science content in a hands-on, inquiry manner, some specifically designed for elementary education majors. The following does not attempt to relate all courses created with a similar design, but to show the diversity of classes that have been created recently around the country. At the University of Portland a course designed for education majors but open to all non-science majors was created. According to Tolman (1999) the sophomore level "Natural Science Course" they have developed covers a variety of science topics, all of which were taught in a manner designed to keep the students active in their learning. Results of this course include a "marked decrease in [the students'] fear of math and science courses" (pg. 45). Western Washington University developed a course that was designed to be a "capstone" that would integrate the content learned during core science courses by providing investigative situations for elementary education majors to apply what they have learned. After taking this class, students had a greater confidence with and understanding of inquiry science (Morse, 1999). At Clemson University a physical sciences course for elementary education majors has shown significant results. Instead of the traditional design of a lecture followed by a lab situation, science concepts were taught in a format where content was integrated with application. Students who took this course were three times more likely to agree to the statement "'I look forward to teaching physical science.'" and the students' attitudes towards science was more positive after the experience (Fones et al., 1999).

Research on three different courses around the country that were designed for education majors and based on teaching the content of Biology using the inquiry methods recommended by the NSES have been found. Pennsylvania State University created an integrated science course whose central focus was the microbial world. The course was created by a collaborative team including professors of chemistry, physics, molecular biology, and science education (McLoughlin &Dana, 1999). Qualitative research gathered resulted in two assertions. The first is that "learning science was most meaningful…when it was framed within a context of pedagogy," (p. 78) and the second was "activities based experiences, pedagogically-oriented assignments and the development of classroom community" were the factors that lead to an increase of student confidence and learning in their classroom (p. 80). At St. Cloud's University, Hall (1992), describes "Biology for Elementary Teachers," a three credit undergraduate course. Teaching methods used include "inquiry and problem solving using a variety of hands-on/minds-on, process oriented activities," (p.239) that were shown to be "influential in promoting positive attitudes toward science and science teaching…" (p.240). Stallheim-Smith and Scharmann (1994) found that by creating an atmosphere where the "personal needs, learning styles, and interest orientations of elementary education majors" (p. 170) were met in a special recitation section of their "Principles of Biology" course there were significant results in achievement. Students in this section scored higher in average grade distribution when compared to other sections taught by the same instructor, sections taught by other instructors during the same semester (p.175), and when compared to the cumulative data for the previous ten years (p. 176).

All of the courses designed to science content in an inquiry manner, and especially those that integrated the pedagogy of teaching, showed positive results. The vast majority of the research shows positive affective results. Students were found to be more interested, more likely to take other science courses, and more comfortable with science. Only Stallheim-Smith and Scharmann (1994) presented results that measured the content learned by the students, and the course on which they reported was a specialized recitation section. Positive affective results have been shown to be the result of courses designed to teach science content, but more research needs to be done to determine if the students learn the content of the subject in such courses.

Methods

Design

A quasi-experimental pretest/posttest design was used for this study. Students who were enrolled in Biology 100 and Biology 110 were the basis for the groups who were involved. Those in Biology 100 were introduced to biological concepts through a traditional lecture and laboratory format consisting primarily of didactic teaching coupled with teacher demonstrations. Students were expected to have read the information in their textbook regarding the topic prior to the lecture. Students participated in a once a week lab section taught by graduate teaching assistants from the department of Biology where they experienced experiments related to the topics covered in the lectures and their reading.

Biology 110 was designed to teach the same topics as Biology 100. However, students would participate in hands-on investigations that integrated scientific methodology with educational pedagogy. The class met twice a week, once for a four-hour lab experience and once for a one hour recitation. During the lab meetings small groups of students worked together on investigations presented in a 5-E inquiry method as proposed by Bybee and Landes (1990). The recitation met to discuss problems students were having understanding concepts, elaborate on the concepts presented in the lab, and provide time for student reflection and discussion. Students were expected to read their textbook after being introduced to the topic from the lab experience.

Biology 100 and 110 both have the aim of teaching the same biological concepts. Biology 110 embeds them in the learning experiences involving hands on investigations and inquiry and couples the content of the course with science teaching pedagogy. Through a pretest/posttest given on the first and last day of classes to both groups this study is designed to determine if how the information was presented would result in a difference in the learning of the biological concepts between the two classes.

In order to determine if there is a significant difference in learning, the pretest and posttest mean scores of the Biology 100 and Biology 110 students were compared using an Analysis of Variance (ANOVA) statistical analysis. Hypotheses, mentioned above, were answered according to the six groups of data

Subjects

All subjects participating in this study were undergraduate students at the University of Nevada, Reno (UNR). The majority of students were freshmen or sophomores, and all were enrolled in Biology 100, *Principles and Applications of Biology*, or Biology 110, *Biology for Education Majors*. All students participating in Biology 110 (n = 15) were students who had been accepted as students in the College of Education or were planning on entering. The subjects in Biology 100 (n = 194) represented non science majors from departments and colleges throughout the university, including elementary education majors (n = 14). Biology 110 majors were few in numbers due to the fact that this was the first time that the course was taught, but reflect a small to average lab section in Biology 100.

Instrument

The National Association of Biology Teachers (NABT) Content Biology Test was developed in conjunction with the National Science Teachers Association (NSTA) as an exit exam for Honors placement in college level biology courses. Content biology was measured by using a pre / post test design on a modification of the (NABT) Biology Content Test. In a previous study, thirty questions had been selected from the NABT test and administered to general Biology courses at the University of Nebraska, Lincoln (Bruning & Glider; unpublished). Test questions were selected using a broad range of content and several evaluative (process skills) questions. The validity and reliability were not changed from the Bruning and Glider study, but were within acceptable ranges. Content validity was reviewed by Dr. Alan Gubanich, UNR and was approved for this study.

Variables

The dependent variable in this study was the score on the NABT exam of the Biology 100 and Biology 110 courses. The independent variable in this study was the difference in the teaching strategies that were used between Biology 100 and Biology 110. Specifically, the hands-on inquiry approach to teaching Biology 110. Intervening variables in this study included gender, number of subjects and the fact that the number of subjects included all available and willing participants in the study.

Procedure

On the first day of class for both Biology 100 and Biology 110 copies of the NABT Biology Test were given to students who were asked to answer the questions to the best of their ability. The participants were made aware that their answers on this test were going to be used for research purposes and would not be looked at until after the course was over, and that participation would in no way effect the grade they received in the course. Any student who did not want to be part of the study was given the option to not take the test. However, 5 points of extra credit (a non significant number) was offered for participation in the study. Participants were asked to write on the test their declared major or pre-major. As students finished, tests were collected and stored for the duration of the semester.

On the final day of classes, students were given copies of the NABT Biology Test identical to those, which had been taken on the first day of the course, and were asked to answer to the best of their ability. Again, they were asked to write their declared major or pre-major. Participants were told that the tests were given for research purposes, and that their participation would in no way effect their grade in the course. As students finished the test they were collected and stored for analysis.

Data Analysis

Data was collected in the form of pre and posttest scores from the NABT Content Biology Test from those who participated in Biology 100 and 110. Analyses were run on the pretest scores of those in Biology 110, elementary education majors in Biology 100, and all students in Biology 100 to determine if they were homogeneous groups at a .05 alpha level (p-value). Additional t Tests were run on each group separately to determine if they had a pre-post test difference. An ANOVA was run to find if there was any significance between the pretest / posttest means of the groups, and a Newman-Keuls multiple comparisons test was used to determine where the significance differences occurred.

Results

Initial ANOVA testing concluded that there was no significant difference (Alpha .05) between the three groups on pre-test mean scores. Thus the groups could be considered homogeneous groups at the onset of the study.

Hypotheses one through three were initially explored with t Tests, with significance to be determined at the .05 level. These hypotheses addressed whether there were differences within each individual group. The only group that showed a statistically significant difference from pretest to posttest was the experimental Biology 110 group, with a p-value equal to .006. (See Table 1)

Table 1

Group Mean Score Comparison between Biology 100 and Biology 110 students

Group	N	NABT pretest	NABT posttest	Mean difference	p-value
Biology 100 (All students)	194	12.39	12.33	-0.055	0.91
Biology 100 (Education Majors)	14	11.30	11.07	-0.24	0.92
Biology 110	15	15.13	20	4.8	0.006

In order to determine the existence of significance between the groupings an ANOVA was run. The ANOVA showed significant difference ($p < .001$) between the groups using all scores (both pre and post). A Newman-Keuls multiple comparison test determined that at the .05 alpha level there were statistically significant differences between the posttest mean scores of those in Biology 110 (the Elementary Education majors experimental section) and the posttest mean scores of both the elementary education majors in Biology 100 and the group of all students in Biology 100 (both traditionally taught). (See Tables 2 - 5)

Table 2

Independent Group Analysis between Biology 100 and Biology 100 students

Group Name and Number	Mean	SD	N
Biology 110 Pre-test (1)	15.13	3.87	15
Biology 110 Posttest (2)	20.00	4.98	15
Biology 100 Ed. Majors			
Pretest (3)	11.30	5.26	13
Biology 100 Ed. Majors			
Posttest (4)	11.07	6.46	14
Biology 100 All Students			
Pretest (5)	12.39	4.39	194
Biology 100 All Students			
Posttest (6)	12.33	5.49	193

Table 3

Analysis of Variance Table (ANOVA) between Biology 100 and Biology 110 students

Source	S.S.	DF	MS	F	Approx. P
Total	11965.77	443			
Between Groups	993.01	5	198.6	7.93	<.001
Within Groups	10972.77	438	25.05		

Table 4

Newman-Keuls Multiple Comparison Test Between Groups

Newman-Keuls Mult. Comp.	Diff.	P	Q	Critical q (.05)
Mean(2)-Mean(4) =	8.9286	6	6.789	4.041 *
Mean(2)-Mean(3) =	8.6923	5	6.481	3.869 *
Mean(2)-Mean(6) =	7.6632	4	8.078	3.639 *
Mean(2)-Mean(5) =	7.6082	3	8.021	3.318 *
Mean(2)-Mean(1) =	4.8667	2	3.766	2.775 *
Mean(1)-Mean(4) =	4.0619	5	3.088	3.869
Mean(1)-Mean(3) =	3.8256	(Does not test)		
Mean(1)-Mean(6) =	2.7965	(Does not test)		
Mean(1)-Mean(5) =	2.7416	(Does not test)		
Mean(5)-Mean(4) =	1.3203	(Does not test)		
Mean(5)-Mean(3) =	1.0841	(Does not test)		
Mean(5)-Mean(6) =	0.055	(Does not test)		
Mean(6)-Mean(4) =	1.2654	(Does not test)		
Mean(6)-Mean(3) =	1.0291	(Does not test)		
Mean(3)-Mean(4) =	0.2363	(Does not test)		

*shows significant differences.

Table 5

Homogeneous Populations, groups ranked

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**Gp Gp Gp Gp Gp Gp

  4  3  6  5  1  2
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**This is a graphical representation of the Newman-Keuls multiple comparisons test. At the 0.05 significance level, the means of any two groups underscored by the same line are not significantly different.

Conclusions

Findings indicate that the within groups hypotheses one through three there existed a significant difference only between the pretest and posttest mean scores of those who participated in Biology 110. Therefore, hypothesis one is rejected, as significant differences were found. Hypotheses two and three were accepted by the results. There were no significant differences between the pretest and posttest scores of elementary education majors taking Biology 100 or in the scores for all students in Biology 100.

Hypothesis four stated that there would be no statistical difference between the posttest mean scores of the elementary education majors who took Biology 110 and those who took Biology 100. This hypothesis is rejected. A significant difference ($p = .05$) between the posttest mean scores was found. Hypothesis five is also rejected as the ANOVA showed that there was also a difference in the posttest mean scores at the .05 level between elementary education majors in Biology 110 and the students of all majors who participated in Biology 100.

Therefore, the instructional format (inquiry and hands-on) used in the Biology 110 course for Elementary Education majors did prove to make a significant difference in biological content learned in the undergraduate course.

Discussion

Although this study concluded that the instructional style of inquiry and hands-on labs proved to be significantly superior to traditional means of instruction, there were some points of discussion that should be made. All efforts were made to insure that both Biology 100 and Biology 110 covered the same topics through aligning the syllabus of Biology 110 to that recommended by the department of Biology, however, each professor in Biology 100 is given some freedom to adjust the course. Therefore, the topics covered in the different courses may not have been covered in equal depth or breadth.

The questions taken from The National Association of Biology Teachers (NABT) Biology Exam, the instrument chosen to assess the learning of the students, were previewed by a professor from the department of Biology. The questions used on the instrument were considered by the professor to be both valid and cover topics that should be included in Biology 100, regardless of the professor. However, with the differences in teaching style and preference of topic, there were no guarantees that all the questions would ask precisely what students had studied in their courses.

The significance of this study is considerable. Several previous studies have found that elementary education majors show a marked increase in attitude toward science and confidence with the subject when the learning of science content is combined with pedagogy (Watters & Ginns, 2000; Shroyer et al., 1996), however, these studies are qualitative in nature and deal with the affective nature of science. Only two other empirical studies have been found on the subject and none (to this date) demonstrate, empirically, whether or not students show an increase in content learning in such an environment as Biology 110.

Additionally, hands on inquiry approaches to teaching are significantly more expensive in both resources and faculty time. Though reform in education at all levels has been called for in order to increase the science literacy of the population at large (NRC, 1996), courses that conform to such recommendations require that a college or university invest greater amounts of money and faculty resources in their design and teaching of introductory science courses. Demonstrating, with this study, that more content knowledge is learned and retained over a semester and that positive affective results are eminent when compared to traditional teaching methods, may help to justify the expense of separate core science classes for prospective teachers.

Affective data was collected in this study for both populations, Biology 110 and Biology 100, regarding student attitudes toward science and science teaching. Although the quantitative data has not yet been examined, anecdotal conversations with both populations show that the education majors in Biology 100 did not have such a positive experience and thus their attitude towards teaching and learning content biology seemed to be lower than those who took Biology 110. The quantitative data needs to be explored to verify the anecdotal conversations and subsequent courses should be analyzed to confirm that positive changes in attitude occurred in this setting.

To extend this research, other experimental core science courses (physics, chemistry, and earth science) for elementary education majors, using a similar design, should be constructed and empirically analyzed. Such courses could create a hands on, inquiry based science program designed to elevate content understanding and a broad familiarity of the sciences for a population, both prospective and practicing teachers in addition to elementary students, where such a demand exists.

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SCIENCE STANDARDS SURVEY: WHAT GEORGIA'S ELEMENTARY TEACHERS TELL US

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Preparing teachers for their professional careers is indeed a formidable task. Meeting the Georgia state standards/Quality Core Curriculum (Georgia Learning Connection, QCC, 1999) and national standards in all content areas is a serious mandate discussed by not only educators and policy makers, but also highlighted in the media. With pressures from the media, parents, and legislators to meet "Standards" in all content areas, it is easy for classroom teachers, as well as educators who prepare them, to feel overwhelmed. The National Research Council recognizes that the daunting task of meeting standards requires the help of all Americans and not just teachers (1996).

The individual teacher is "the engine of change" in classroom instruction (Fullan, 1993). The public demand for accountability demands a special type of teacher who is well prepared and not afraid to take on the challenge of meeting standards (Loucks-Horsley & Matsumoto, 1999). Classroom teachers may be unable to meet the new demands not because they do not want to address standards, but because they may lack the content knowledge and pedagogical skills necessary to teach the new, more stringent standards (Darling-Hammond, 1997). Are teachers prepared to translate theory into practice and as Darling-Hammond (1997) suggests, do they feel unprepared to meet the pedagogical and content demands of the contemporary science classroom? Recently, the Glen Commission Report (Peterson, 2000) made two recommendations for science education that appear relevant to the issue of attaining state and national science standards. The first is the creation of a continuous system for grades 1-12 to improve the quality of math and science teaching, and the second is the improvement of the teaching preparation of science and math teachers.

In our science methods classes, preservice teachers indicated through informal conversation and written reports that many of their field placement teachers de-emphasize science instruction in their daily instructional delivery. In the graduate science methods' class, inservice teachers reported a lack of emphasis in their schools on teaching science standards. We believed that inservice teachers could tell us what they needed to know to meet the standards since they had taken science courses during their undergraduate program and were responsible for teaching the science standards at their particular grade level. Our graduate students, who are K-5 inservice teachers, told us in class that science was often not included in classroom instruction because reading and math were the more valued subjects in their schools. Some even went so far as to state that their principals did not expect them to teach science, but would rather have them devote their time to reading and math. In a recent study, Akerson (2001) supported their observations, "While some teachers may be specifically told *not* to teach science, most are being asked only to *emphasize* language arts" (Akerson, 2001, p. 43). Many K-5 teachers' first learned of the state and national standards in the graduate science methods course and, for a few, it was the first time they had read them. Our concerns about the quality and amount of time spent on science instruction grew as the preservice teachers enrolled in our undergraduate science methods classes reported that they observed little science being taught during their field placements and heard few, if any, references to the state or national science standards.

As a result of the input from inservice and preservice teachers about science instruction in classrooms, we decided to survey inservice teachers and ascertain how university science educators could better prepare preservice teachers to be science teachers. With that goal in mind, the purpose of this research was to explore inservice teachers' beliefs about what instruction and content they had received in their teacher preparation program and based on that experience, what was needed in a teacher preparation program in order to be better prepared to teach Georgia's science standards. Questions were developed that explored the relationship between professional science standards and teacher preparation. The questions focused on three areas: 1) Preservice teacher course work; 2) Current implementation of Georgia science standards; and 3) Assistance needed to increase the teaching of standards.

Method

Subjects

The subjects (N=462) in the study were K-5 inservice teachers employed in western Georgia. These were chosen because of their proximity to the researchers' university. The school districts were generally diverse with a 65% Caucasian and 35% non-white student population. The survey population of teachers was predominately female and drawn from elementary schools within 45 miles of our institution. The greatest percentage, 39%, of respondents had 1-5 years teaching experience, followed by 28% with 15 or more years of experience, 21% with 6-10 years, and 12% with 11-15 years. Kindergarten and third grade contributed the largest percentage of respondents with 20%, followed by first grade at 17%, second grade at 16%, and fourth and fifth grades, 13% each. Thirty-four percent of the teachers had a Master's degree, and 10% had a Specialist degree, a Master's plus 27 credit hours.

Procedure

During the academic year 1999-2000, school principals and science coordinators distributed surveys to teachers, which when completed, were either returned to a central collection point in each building or mailed in an enclosed self-addressed stamped envelope.

Completion of the survey was voluntary. Since anonymity of participants and school districts had been assured in the contact letter, personal contact was not made to increase the rate of return for the surveys. Response rate for the survey was 46%. Schloss and Smith (1999) state, "Without a follow-up, you can expect about a 30 percent return rate" (p. 67). A return rate of 50% is considered adequate for a descriptive type of survey according to Babbie (1992); therefore, since the 46% return rate approaches the 50% rate considered adequate, the findings can be supported by the number of surveys returned.

The Instrument

In order to ascertain teachers' perceptions of their preservice education, K-5 teachers were questioned using a combined quantitative and open response instrument consisting of six questions. Questions were developed from a review of literature and preservice and inservice teacher conversations and written reports. A review of literature helped researchers formulate questions concerning courses in the teacher preparation program and problems encountered by inservice teachers teaching science in the elementary classroom. Thirty-one inservice teachers reviewed the instrument and edited the questions. To test the survey and establish content validity, the instrument was piloted among 26 graduate inservice K-5 teachers. They critiqued the survey and made suggestions for refining the items. In addition to the teachers, eight professors in the College of Education provided written feedback on the instrument.

Data Analysis

Descriptive statistics were used to analyze the data and results were reported in percentages. Reliability was assessed through the test-retest procedures recommended by Airasian and Gay (2000). Fifty K-5 graduate education students completed the survey in class and then completed the survey again in 1-2 weeks. Item analyses were completed using chi-squares. The average consistency of responses was 82%. Fifteen of the 22 chi-squares were significant indicating consistency between pretest and posttest results. The chi-squares not significant reflected low frequencies in three of the four cells.

Results

Percentage analysis was used to represent the respondents' perceptions and recollections (Bieger & Gerlach, 1996). The following six questions with their responses are as follows:

Question 1: Circle your undergraduate science courses and rate your satisfaction with each course in preparing you in the content necessary to teach elementary science.

Four hundred sixty-two teachers responded to the survey. Teachers identified each of their college science courses and rated their satisfaction with each course in preparing them to teach science content using a Likert scale with "5" being most satisfied and "1" being least satisfied. Eighty-four percent reported taking biology and 51% of this group indicated that they were satisfied with biology's content for teaching elementary science. Geology and science methods (71%, 70%, respectively) were courses taken by approximately the same number of teachers with the satisfaction rate for preparation to teach science reported as 66% and 53%. Environmental science, astronomy, chemistry, and physics (44%, 43%, 43%, 40%, respectively), accounted for the remaining science content courses taken with satisfaction rates in the content of these courses rated at 68%, 23%, 10%, and 12%, respectively. It appears that the most commonly or frequently taken science courses, biology, science methods, and geology had the highest satisfaction rates, with the exception of environmental science.

Question 2. Circle the courses that prepared you for teaching the Georgia science standards at your grade level.

Forty-four percent of teachers reported that they gained most of their ability to teach the professional standards for their grade level from their *science methods* course. Biology, environmental science, geology, astronomy, and physics courses (27%, 16%, 17%, 10%, and 3%, respectively) prepared teachers to teach science to their elementary students. Twenty-seven percent of teachers reported that *no science course* prepared them to teach standards. This percentage is larger than any specific *content* course, with the exception of environmental science. Teachers report that their degree of preparation and knowledge of the content needed to teach science comes from their *science methods course*, not content specific courses.

Question 3. Circle how prepared you are to teach the K-5 science standards at your grade level.

Nineteen percent of teachers (19%) reported that they were "very prepared" to teach science standards, while the largest percentage (45%) of teachers indicated they were "prepared". Thirty-six percent reported they were "somewhat prepared" or "not prepared". As a group, teachers appeared to signal that they felt prepared to teach their grade level science and overwhelming refuted that they were unprepared to teach the science standards. Still, 36% is a sizable proportion of teachers that appear to need for more "help" in science teaching.

Question 4. Circle the degree to which you teach the science Georgia science standards at your grade level.

Over one third (37%) of the teachers reported they "teach beyond the Georgia science standards", 41% "meet all science standards", 17% "do some science standards", while 5% "don't use the science standards". The majority of teachers report they are teaching all of Georgia's science standards.

Question 5. If a teacher responded to the question, "Do you use some of the standards" or "Don't use them", in question 4, he/she was asked in an open-ended format, "What do you believe inhibits you from teaching the Georgia science standards or doing more?"

Teachers who responded, "Do use some of the standards" or "Don't use them", in question #4 (n=100) reported that a lack of time (55%) was the key inhibitor. Emphasis on reading and math (33%) and lack of materials (31%) were identified as two other reasons for not teaching the standards. Fear associated with lack of knowledge (13%) and departmentalization by subjects (12%), were also given as reasons for not addressing standards.

Question 6. All subjects were asked, "What assistance they could use in teaching the Georgia science standards?"

Teachers indicated the need for science supplies (77%). The need for more instructional time (67%), science training (41%), and a new curriculum (29%) were also listed. Georgia teachers perceive more money for supplies and more instructional time as the most important types of assistance that would enhance their ability to teach the standards.

Discussion and Conclusions

This study was conducted to explore inservice teachers' beliefs about what they had received and what they needed in preservice teacher preparation program in order to be better prepared to teach Georgia science standards. Teachers are the key to achieving the science education standards (NRC, 1996) and must be well prepared to meet the standards' new demands (Loucks-Horsley & Matsumoto, 1999), yet some feel unprepared for the new pedagogy and knowledge content of these standards (Darling-Hammond, 1997). Even with 64% of the teachers reporting they feel prepared to teach the standards, 36% acknowledged they are only "somewhat prepared" or "not prepared" to teach the standards. This statistic represents a sizable number of teachers who acknowledge the need for assistance. This need must be addressed in order to ensure that elementary age students who depend on those under-prepared teachers will have the opportunity to excel in science, as they do in other subjects.

Elementary teachers are not afforded the luxury of choosing a science specialty, but must be prepared to meet the science standards in a variety of science disciplines, often within a single grade level. The K-5 Georgia standards include: physical, life (including ecology), earth and space science and the inquiry and process skills. There are 29 physical science standards, 21 life science standards, and 14 standards for earth/space science. Physical science standards appear more frequently than any of the other science field standards, yet teachers were least satisfied in their level of content knowledge and in their preparation to teach physical science concepts. Teachers reported, of the content sciences, they were most satisfied with the content and preparation of their environmental science course, yet this science field has only six standards and is embedded in only one grade level in Georgia. Many more teachers took environmental science classes as compared to those who chose to take physics, yet Georgia's K-6 science standards expect a teacher to teach more physical science than environmental.

The goal of scientific literacy for all children begins in the early years of education (NRC, 1996). To achieve this goal, strengthening the science preparation of preservice teachers is essential. The Glenn Commission Report on Science and Math Teaching (Peterson, 2000) recommended an ongoing system to improve math and science teaching, a substantial increase in the number of science and math teachers and an improvement in the quality of their teaching preparation programs. A little over half the teachers in this survey indicated that they acquired most of their ability to teach the Georgia science standards from their science methods courses and not content specific courses. Another twenty-seven percent reported that no science course, either content or pedagogical, prepared them to teach the standards. These numbers are strong indicators for change. Even though teachers report they get their ability to teach the standards from science methods, it is questionable as to whether they receive the content needed for the standards in a pedagogy/methods course. If teachers are expected to deliver student test scores that reflect an increase in science knowledge that encompasses a number of science content fields, more attention must be paid to the standards and course requirements during the preservice teacher years. In our institution, students choose their science courses and only the number of science courses taken is important for fulfilling university requirements. It is important to note that a student could graduate in teacher education with two biology courses and a lab and have no courses in earth and space science or physical science.

The majority of Georgia's inservice teachers indicated they would like more time and materials for science instruction. Teachers reported that science had a lower priority in some schools or with school administrators than math and reading, both of which are routinely tested through state assessments. Accountability for science learning may play a key role in increasing the instructional priority for science. At the time this study was conducted, science standards were not included in Georgia's state testing program. The lack of accountability could be a reason why some teachers indicated that science was not always being taught in the elementary schools in the surveyed area. Teachers perceived that factors beyond their immediate control, time constraints and administrative directives that emphasize other subjects, were prime reasons for not addressing science standards.

Recommendations

The effectiveness of inservice teachers' science instruction and the condition of science education in elementary schools has been under intense scrutiny for years. To increase content knowledge and pedagogical skills, preservice teachers should be required to take at least one science course in life science, earth and space science, and physical science. Courses should be specifically designed so that the pedagogical approach used in the class and the science content delivered prepares them to teach the science standards in elementary classrooms.

A change that would address the preparation and content problems involves colleges and departments of education inviting other university science departments to share in program requirement decisions. Involvement of this nature requires considerable time commitment on the part of all faculties, relinquishing of traditional territories and substantial compromise. In our institution, some science faculty in the College Arts and Sciences and the College of Education have discussed the standards and have begun team teaching some science courses. We believe that this approach will result in a better-prepared preservice teacher who can teach science content and skills, as well implement state science standards. University departments and colleges campus wide must come together and collectively work to enhance the knowledge and skills of future teachers in order that they may meet not only the required academic standards, but also the educational needs of all elementary school students. All parties will benefit for it is those elementary school students who will be the students in not only the education courses, but also all programs campus-wide in the future.

Changes that would increase skill in teaching science would involve using the physical science concepts to conduct demonstration inquiry lessons in science methods classes. The concepts of light and sound, which are often difficult to teach, could be demonstrated and practiced by preservice teachers in their university class. The use of computer simulations when the real materials are not available for hands-on activities, and the use of case studies could also increase the preparation for the teaching of all science standards. Further research into other teacher preparation programs nationwide and their science content requirements might shed light on how the issue of more diverse science content can be required of students.

A scientifically literate society is the vision of the National Science Education Standards (1996). These standards emphatically state, "Students cannot achieve high levels of performance without access to skilled professional teachers, adequate classroom time, a rich array of learning materials, accommodating work spaces, and the resources of the communities surrounding their schools." (National Research Council, 1996, p.2).

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DEVELOPMENT OF AN ELEMENTARY EARTH SYSTEMS SCIENCE AND MATHEMATICS CURRICULUM

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Satellite and surface based technologies and observations have contributed greatly to scientists' knowledge of the Earth's intricately connected systems. Yet, despite the rapid growth of Earth system science as an interdisciplinary field of inquiry, there remains a great need for educators to provide resources and meaningful learning opportunities for elementary school children that will help them recognize and begin to understand the significance and delicate nature of our environment. Such is the intent of this project. We aim to provide integrated learning opportunities for primary children that will help them:

- recognize the interconnected nature of the Earth's systems;
- appreciate the technological tools (e.g. satellite imagery) that scientists use to conduct Earth system science;
- recognize the extent to which mathematics, science, and technology are not only connected to each other, but also can serve as tools to help us understand natural phenomena; and
- cultivate a spirit of curiosity and confidence among diverse learners who will be responsible for understanding and caring for the Earth in the decades to come.

In this presentation, the development of an earth systems science curriculum (supported by NASA) that reflects diverse cultural perspectives will be presented. Examples of lessons from the CD/website will be shared along with formative assessment data.

Theoretical Perspectives

National reform initiatives in both mathematics and science are replete with references to the integration of, and symbiotic relationship between, mathematics, science and technology (e.g., National Council of Teachers of Mathematics [NCTM], 1989; American Association for the Advancement of Science [AAAS], 1989; National Research Council [NRC], 1996). The American Association for the Advancement of Science (AAAS), for example, has suggested that "science provides mathematics with interesting problems to investigate, and mathematics provides science with powerful tools to use in analyzing data" (p. 17). Similarly, the National Council of Teachers of Mathematics' (NCTM) Standards documents draw heavily on the idea of connecting mathematical concepts and tools to the scientific contexts in which they are naturally embedded.

Encompassed within this broader vision of interdisciplinary curricula and pedagogy are calls for increased attention to specific content areas and concepts. Notable among these areas is the study of the complex interactions of the Earth's systems. The AAAS (1990), for example, highlights the importance of understanding how the "linked and fluctuating interactions of life forms and environment compose a total ecosystem; understanding any one part of it well requires knowledge of how that part interacts with the other" (p. 65). Similarly, the *National Science Education Standards* (NRC, 1996, pp 130-134) articulates specific content standards in Earth system science for elementary school learners that include opportunities for them to:

- observe closely the objects and materials in their environment;
- observe changes in cycles, temperature, seasons, weather, movement of water, etc.;
- identify properties of Earth materials, and recognize the constantly changing nature of the Earth's surface due to erosion, weathering, landslides, volcanic eruptions, earthquakes, etc.

The national science standards also emphasize the growing importance of technology in fostering scientific inquiry and understanding – specifically, "the relationship of science and technology and the way people are involved in both" (NRC, 1996, p. 135).

Our premise is that different cultural perspectives are essential for understanding earth systems science and students must cross cultural borders when learning western science. According to Aikenhead (1997), every culture has a knowledge system that describes and explains science. Such border crossings may be facilitated when science curriculum is developed using local knowledge and values from indigenous cultures (Aikenhead, 2001).

Program Goals

Using the national curriculum reform goals as guiding principles, an integrated, K-5 earth systems science curriculum program is being developed which has at its core the following fundamental objectives. Specifically, the intent of the project is to:

- build upon existing data, technologies and resources (e.g. NASA satellite imagery and programs) in the creation of approximately 50 thematic, integrated, stand alone activities that are cohesively connected across K-5 grade levels. These activities will not only scaffold upon each other horizontally (across one grade level), but also vertically (over multiple grade levels). The curriculum will reflect national content and process standards for elementary level mathematics and science education.
- develop modules around real world, scientific, and cultural contexts that resonate with all learners, particularly children from typically disadvantaged and underrepresented populations.
- support the curriculum activities by developing a compact disc through which students will enter and access data on the web, observe satellite imagery, post findings, and investigate earth systems science at local school sites.

Cultural Connections

These three curriculum modules are being nationally field tested at sites that reflect diversity in cultures and ecosystems: rural southwest Virginia, rural and inner city Colorado, and rural South Dakota. The curriculum is designed to reflect cultural values embedded earth systems science at the different locations. Through stories embedded in the curriculum that reflect a diversity of cultures, the following cultures are represented in the curriculum. Appalachian culture in Virginia, Hispanic migrant workers in Colorado, African-American culture inner city Denver, and Native American culture in South Dakota.

Curriculum Modules

Three curriculum modules are being developed for the 2001-2002 academic year: (1) Greenlinks; (2) Global Visions; and (3) Migrations del Mundo. Access to these modules and lessons by connecting with the Earth Systems Connection website: http://www.tandl.vt.edu/esc/. A brief description of each module follows:

The Greenlinks learning module is designed to help students understand how green plants play an essential role in earth systems science. In this module, students are encouraged to investigate local habitats such as school playgrounds, local plants, and ecosystems in the region. By documenting changes in the habitats, plants, or ecosystems throughout the school year, students will understand factors affecting environmental changes. Through satellite imagery, students will learn how vegetation changes throughout different seasons on a global scale. Indigenous stories reflecting seasonal changes will be incorporated in this module.

In the Global Visions module, students begin to investigate the ways in which satellites help to "see" the earth from a vantage point that would otherwise be impossible. Throughout the lessons in this module, students gain a basic understanding of what satellites are, what they look like, how they take and create images of the earth, and what these images from space look like. This foundational information about a satellite's use and function will provide the basis for many of the activities in other units. Students will investigate imagery by using digital cameras to simulate satellites. Mosaic patterns created by pixilated images will be investigated with analogies to patterns in indigenous art.

In the Migrations del Mundo module, students will explore reasons for migration, migrational cues, photoperiods, and migrational paths. Using data from satellites, students will track the paths of various animals (e.g. Swainson's hawk, osprey) in relation to seasonal changes in vegetation. Students will learn how to analyze data through graphing with coordinate systems. Animal migrations stories from indigenous cultures will be embedded in the module.

Formative Assessment

The curriculum is being nationally field tested in three diverse locations. Data collected includes video taped and audio taped session with teachers, school observations, artifacts created by children, and surveys on the effectiveness of the lessons. From the survey data, teachers were very positive about the lessons, use-of-technology, and the likelihood they would implement the lessons in their classroom (see table 1).

Table 1

Average scores on ESC Project Evaluation

Teacher Friendly	Student Friendly	Appropriate Difficulty	Student Directions	Teacher Directions
4.74	4.53	4.4	4.40	4.7

Science Level Appropriate	Math Level Appropriate	Technology Level Appropriate	Teacher Comfort with Technology	Implementation Likelihood
4.26	4.27	4.31	4.53	4.43

Note: n=120; scores based on Likert scale (5 strongly agree. . . 1 strongly disagree)

From our interview data, we learned that the articulation of lessons among grade levels remains a challenge. Primary teachers expressed concerns about the abstract nature of the data collection for children and the need for developmentally appropriate lessons for young children. For example, in discussing the Global Green Up Lesson, one primary teacher suggested that the extrapolation of vegetation color images from a global satellite map to a chart by coloring in matching colors would be very difficult for young children. The teacher explained:

> Instead of coloring in these little blocks like this, maybe you could have that map so you could color it on the map instead of a little box. . . it's not that we don't work with it and it's not that we don't introduce it but where they are developmentally, they are very concrete learners and this is very abstract.

A second teacher supported this suggestion by stating, "For first graders to make the leap from the globe to that [flat global satellite map] is huge." In response to this concern, ESC curriculum developers by shared a plan to develop a concrete activity to wrap paper around a tennis ball to show how a global map is created. Other teachers suggested mapping satellite data from individual states: however, the curriculum developers explained the constraints of finding available satellite data. It was also pointed out that this lesson was designed for fourth or fifth grade; nevertheless, the problem of articulation of lessons among grade levels was salient in further discussion.

From our interview data, teachers were positive about integrating earth systems science with different cultural knowledge and perspectives. Teachers were also excited about the possibility of communicating with teachers from another culture or geographical location. One teacher thought that collecting longitudinal data over time in familiar areas (e.g. playgrounds) and sharing that data with other schools was worthwhile. She explained:

> What I like to do is gather data year long because a lot of these things are long projects like seasons, watching plants and transpiration . . .they are meaningless if you just do it once. You need to do them a long time but what would be neat

> would be to gather data one year, and you could use it the year because you may not get the opportunity to do it more than two or three times, but when you have a background of data . . .it would be neat to compare what you have in Virginia with South Dakota because it is so different there and also the inner city environment.

Even though teachers supported the sharing of data through pen pals or other means, communication and use of technology remains a significant barrier for teachers with limited time for internet access and skills related to digitally collecting and importing data (e.g. scanning, digital photography, attaching documents). The challenge for curriculum developers is to develop interfaces with the curriculum and CD to facilitate communication and a support system for integrating technology into the curriculum.

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EXAMINING THE INFLUENCE OF A GRADUATE TEACHING FELLOWS PROGRAM ON TEACHERS IN GRADES 7-12

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A huge investment in public funding, approximately 10 million dollars for the 2002 fiscal year, has been dedicated to the implementation of the National Science Foundation's (NSF) Graduate Teaching Fellows in K-12 (GK-12) program (NSF, 2001). In these GK-12 programs, graduate level scientists known as Graduate Teaching Fellows (GTF) are placed in K-12 science classrooms to act as resources for science teachers. The NSF's investment is aligned with reform documents which call for scientists and the science education community to work together to realize the goal of scientific literacy for all (American Association for the Advancement of Science (AAAS), 1993; AAAS, 1998; NRC, 2000; NRC, 1996a; NRC, 1996b). Although much research has been done on factors that influence science teachers' views of science, and ultimately the way science teachers interpret and deliver science content, little research has been done on the impact that this type of program will have on science teachers' teaching practice.

The purpose of the research presented in this paper is to examine the impact on the science teachers involved in a NSF GK-12 program. This program was implemented at a large southeastern university and the local school district. Data were collected on one cohort for one academic year using qualitative methods of observation and interview.

Literature

The current reform in science education in the United States includes a call for scientific literacy for all Americans (American Association for the Advancement of Science (AAAS), 1989; AAAS, 1993; AAAS, 1998; National Research Council (NRC), 2000; NRC, 1996a; NRC, 1996b). Reasons given for the necessity of scientific literacy include a fairer distribution of economic opportunities and the important role of scientific and technological understanding to inform public and private decision-making. A key component of scientific literacy is a sound understanding of the nature of science (NOS) (NRC, 1996a, NRC 1996b). In this study Lederman and Zeidler's definition of the NOS, "the values and assumptions inherent to the development of scientific knowledge" (1987, p.721) will be used. A science teacher's understanding of the NOS plays an essential role in efforts to improve scientific literacy (NRC, 1996a, NRC 1996b). The view of the NOS held by the science teacher influences the curriculum offered, which in turn influences the view of the NOS held by students.

The relationship between teachers' understanding of the NOS and teacher practice has been studied for over ten years. The result of this research is not consistent. Lederman and Zeidler (1987) conducted research with 18 teachers from a variety of contexts and schools examining the impact that science teachers' concepts of the NOS have on teaching behavior. This study found no direct relationship between teacher's perspectives of the NOS and teacher behavior. Duschl and Wright (1989) investigated the manner and degree to which science teachers consider the nature of the subject matter when making decisions about the planning and delivery of instructional tasks. Although these researchers found that science teachers did not consider the NOS in their decision making, they hypothesized that other factors may be inhibiting science teachers' ability to teach in a manner consistent with beliefs.

Benson (1989) theorized that a science teacher's conceptions of disciplinary knowledge are reflected in the curriculum he/she teaches, but also are heavily influenced by institutional factors. Brickhouse (1990) examined the effect of science teachers' beliefs about the NOS on classroom practice. She found that science teachers differed in their views of the nature of scientific theories, scientific processes, and the progression and change of scientific knowledge. However, she found that science teachers' views of the NOS might be expressed in their classroom instruction. Hashew (1996) focused on science teacher's epistemological beliefs and the impact they have on teaching. He found that science teacher epistemological beliefs did influence teaching practice. That is, science teachers who held constructivist beliefs had common methods of instruction, assessment, and treated student knowledge differently than those science teachers holding positivist beliefs. Additionally, further work done by Lederman (1999) examining factors that facilitate or impede the relationship between teacher practice and understanding of the NOS, found that there are factors that may impede a teacher's ability to teach in a manner consistent with beliefs. Among these factors are teachers' level of experience, intentions, and perceptions of students.

The works cited above demonstrate that the view of science held by the science teacher, even when constrained by other forces, impacts how the material is chosen, presented and interpreted for the students in any given class. This selection, presentation and interpretation, in turn, influences the way that students accept and acquire information used to form their own views of subject matter knowledge. These assertions are further supported by research done on pupils' understanding of the NOS (Soloman, Scott, & Duveen, 1996) as well as by policy documents (NRC, 1996a; NRC, 1996b; The National Commission on Mathematics and Science (NCMS), 2000).

The same reform documents that call for scientific literacy urge the scientific and science education communities to work together to attain this goal of scientific literacy (AAAS, 1993; AAAS, 1998; National Academy of Sciences (NAS), 1998; NRC, 2000; NRC, 1996a; NRC, 1996b). The GK-12 programs implemented by the NSF represent one of the first major attempts to form collaborative partnerships between university scientists and K-12 science teachers working together in the school setting. Through these university-school collaborations, the NSF hopes to narrow the gulf between the world of school science and the world of the scientist by increasing the level of scientific literacy among the general population while increasing scientists understanding of K-12 science education (NSF, 2000).

The classroom teacher is the vehicle through which reform efforts in education are realized. Shulman (1987) was the first to conceptualize that classroom teachers had specialized knowledge, which he termed Pedagogical Content Knowledge (PCK), a knowledge base of teaching within specific subject areas . The National Board for Professional Teaching Standards (NBPTS) followed up this conception by articulating five core propositions that effective teachers possess (Standards, 2001) within the subject area they teach. The knowledge, skills and dispositions held by the classroom teacher within these categories influence the delivery of the enacted curriculum. Additionally, the categories of effective teaching provided by Shulman and the NBPTS are representative of the current standard by which effective teaching is measured. For these reasons, it is through the lens provided by the NBPTS and Shulman that this work is reported.

Context of the Study

The GTFs were placed in both high school and middle school science classrooms. In some of the settings, the GTFs worked alone with a single teacher called a Partner Teacher (PT). In others the GTFs were paired to work with a pair of PTs. All of the schools the GTFs worked in had a majority of students that would be considered disadvantaged.

The GTFs were told that their role was to collaboratively plan and deliver hands-on inquiry-based laboratory activities with their PTs. Toward this end a workshop was held prior to the beginning of the school year in which two experienced teachers worked with the GTFs and PTs to demonstrate the types of activities that might occur. Additionally, the GTFs were given access to a large number of hands-on science kits produced by one of the cooperating university's science outreach organizations.

During the school year the GTFs spent ten hours in the science classrooms teaching and five hours outside of class planning and preparing lessons. A seminar was held every other week for the GTFs in which business matters were handled and issues related to their teaching experiences were discussed. The GTFs were expected to turn in lesson plans of the hands-on laboratory activities they had completed that week during seminar, whether or not they had developed the activities themselves. The GTFs also were asked to develop lesson plans within their professional subject area for the entire academic year that might be used by the other GTFs in the program. Additionally, the GTFs took two education courses (one per semester).

Methods

Data were collected from August through May from a cohort of twelve GTFs and 10 PTs. Forms of data collection included both informal and formal interviews, observations of classroom teaching, and observations of PT and GTF interactions. For this paper, informal means that the data were collected without the aid of recording equipment or through the use of a collection instrument. Field notes were taken as soon as feasible after the conversation. Formal, on the other hand, means that the data were collected with the aid of recording equipment or through the use of a data collection instrument. Initial data collection took the form of informal interviews with GTFs and PTs. Additionally, informal observations of classroom interactions between GTFs and their PTs were conducted. From these informal interviews and observations, formal interview questions were formulated based on the goals of this particular grant. According to the grant proposal, these goals for PTs included: 1) an increase in science content knowledge, 2) an increase in the use of computer technology, 3) an increase in the use of specific learning tools such as inquiry-based technology, 4) an increase in communication links with learning communities, and 5) an enhancement of positive attitudes about science.

Interviews

Interviews conducted for this research were semi-structured in nature. Initial formal interview questions (See Appendix A and Appendix B) revolved around individual perceptions of meeting program goals, the impact program participation had on participants, and on ways the program could be improved. The initial interviews were then transcribed and used to generate questions for follow up interviews. In addition, questions for the second round of interviews stemmed from both formal and informal observations done of the interaction between the PTs and GTFs.

Additional questions for the second round of interviews came from the respondents themselves. One of the questions used in the second round of interviews asked the respondents to identify any questions that they would like to ask fellow participants. Respondents were then asked to answer their own question. Each participant's question was then asked of following respondents during their second interviews. All formal interviewing took place during the second semester of the GTF/PT collaboration.

Observations

Informal observations of GTF and PT interactions and teaching were conducted throughout the school year. In addition, a total of 30 formal narrative observations were done in varying classrooms on a rotating basis, completed in a manner to ensure an equal representation of all the contexts in which the collaborations were occurring. All formal observations were done using a narrative observation form (See appendix C). The form construction was guided by a series of questions that were developed based on the goals of this particular program.

Supporting Data Collection

Other data were collected to inform, direct, support or refute findings from formal data sources. Among these forms of data collection were GTF written reflections completed as part of one of the education courses taken by the GTFs. These reflections were read and used to inform directions taken in formal data collection. Additionally, the GTFs participated in a biweekly seminar conducted by the program director that focused on their experiences in the classroom. Discussions during the seminar that focused on topics relevant to this paper were also used to inform the direction and development of data collection.

Data Analysis

Interviews

Formal interviews were analyzed using the constant comparative method (Erlandson, 1993). The first round of interviews were transcribed and coded using the program goals for PTs mentioned in the observation section above as a supporting framework for possible initial categories. The initial coding displayed a large amount of data in two categories, subject matter knowledge and learning communities. Additionally, each of the two categories included a wide variety of information that required further analysis.

At this point the other sources of data were included in the examination of data to determine if they could provide direction for further analysis. A decision was made to include all sources of information in one coding session in the hope that the categories of analysis might become more clearly defined. A second round of coding then occurred. Categories relating to the following themes were identified: Subject matter benefits and detriments, Roles, Knowledge of Teaching in K-12 Arena, Students, Learning Communities, Time/Planning/Impact on GTF, Computer Literacy, and Odds-n-Ends.

The categories were then examined to determine which of these categories applied to the PTs and which applied to the other participants in this program. At this point a decision was made that only three categories clearly contained enough information regarding the PTs to make any interpretations, Subject Matter Benefits and Detriments, Roles, and Learning Communities. However, the data within these categories still was not clearly defined enough to make any interpretations. Questions were then created for the second round of interviews. The questions were based on information gathered from the initial data analysis as well as from the original goals of the program for PTs. That is, the second round of interviews followed a path similar to the initial interviews of focusing on the program goals while at the same time focusing on unique characteristics identified in the initial round of data collection.

The second round of interviews was then transcribed. Following transcription, the data were coded using the existing categories as a background while attempting to pull out distinct differences in the data within each category. As these categories began to develop, the initial data were re-examined to determine how closely aligned the total data collection was to the newly created categories. A decision was then made to only address findings related to the PTs in this paper and to address other findings related to the students, GTFs, and the program in other presentations. The following categories emerged at this point: Subject Matter Content Knowledge, Pedagogical Content Knowledge, and Learning Communities.

The final phase of analysis included taking these created categories and comparing them to the NBPTS five core propositions (Standards, 2001) for teachers and

Shulman's categories of teacher knowledge that make up a teacher's PCK (1987). These documents contain similar and accepted categories of teachers' knowledge. By using these categories as an outline, the categories, which this paper is based on, emerged from the data and are reported below. These categories are, Subject Matter Content Knowledge, Curriculum Knowledge, Knowledge of Learners and Their Characteristics, and Learning Communities.

Observations

The observations were used to gain an accurate picture of the types of teaching activities in which the GTFs and PTs were engaged. Areas focused on during observations included: content covered, types of activities implemented, use of computer technology, roles of the PT and GTF, and the interaction that occurred between all parties in the classrooms. These observations were instrumental in painting a picture of what was occurring in the classroom. Additionally, they served the purpose of generating ideas to be explored during subsequent interviews.

Supporting Data

Field notes, journal entries, GTF written reflections, and informal seminar discussions were used to inform, direct, refute, and/or support findings from more formal data sources. Additionally, a draft of the Findings Section of this paper was provided to all the PTs in this cohort as a final member check. Their feedback was then incorporated into the final version of this paper.

Findings

Analysis of the data collected demonstrates that PTs working with the GTFs increased their understanding of teaching science in a number of ways. Analysis of findings is discussed in terms of Content Knowledge, Curriculum Knowledge, Knowledge of Learners and Their Characteristics, and Learning Communities. Each of these categories is mentioned as being important to teaching effectiveness either by Shulman or in the NBPTS propositions, or both.

Subject Matter Content Knowledge

The collaboration between GTFs and PTs provided opportunities for PTs' to increase their subject matter content knowledge. This growth occurred in a number of forms. One form of this can be seen as a high school PT talks about working with his GTF. As stated by Guy, a PTteaching high school engineering,

> There certainly have been times when I directed toward my GTF to say, I don't know. Most of the time I'm not embarrassed to say I don't know in front of the class. And it is nice having someone that I can refer to and say you might want to ask the GTF about that.

In this form, the subject matter content knowledge sharing was publicly displayed in front of the students in the classroom. Carrie, a GTF working on her physics degree, also frequently encountered this in her collaboration with her PT. During one observation the PT directed the entire class to listen to an explanation she had given to a small group of students. When queried about this incident during one of her interviews she stated,

> He [PT] openly admitted to me in our very first meeting that he didn't have a very strong physics background at all. He is always asking me, "so could you explain this a little more? I don't know this concept. I've never understood it very much."…. He is not afraid at all to ask me, to freely admit, "Well I don't know this. Ms. Adkins [Carrie], can you help us, can you contribute to this?"

During observations of classroom teaching, numerous examples of this public display of subject matter content knowledge interaction between the GTF and the PTs were encountered.

These interactions were unique in a number of ways. In these interactions the PTs were able to interact with subject matter experts on an as-needed basis. Additionally, these interactions occurred in a setting in which the PT were comfortable, their individual classrooms, not a science laboratory or a university workshop. Each of the factors increased the likelihood that the PTs asked questions and gained information of relevance and importance regarding the curriculums they teach. Additionally, both GTFs and PTs agreed during interviews that this was one of the major benefits for the PTs in these collaborations.

These public displays not only provided opportunities for PTs' to increase subject matter content knowledge, they also provided an excellent example for the students in these classes of a type of collaboration between scientists and science educators encouraged by recent science reform initiatives. Collaboration is one element of a learning community, another category of teacher knowledge. Through these public displays, students in these classes were provided with models of scientific interaction that were more realistic than those typically encountered in a school science classroom.

Some examples of opportunities for growth in PTs subject matter content knowledge were not so public. When questioned about subject matter content knowledge, Don, a GTF working on his chemistry degree, states that he and his PTs' subject matter content knowledge conversations occurred in less public forums.

> He claims his chemical background is pretty rudimentary so he looks to me to ask about the periodic table and trends and why those things are, but mostly it's behind, in the absence of students. Just for his own sake of being able to explain to them what these concepts are.

The same phenomena is reported by Carrie,

> So when a particular topic is coming up, sometimes I kind of explain it a little more or whatever and try to enrich his content. So that when he interacts with the kids as well he can kind of have a better understanding.

These statements from the GTFs are supported by interview data collected from the PTs.

PTs reported growth in subject matter content knowledge, especially those areas in which they felt they were weakest. As stated by Kim, a middle school PT,

> I do have weaknesses, like geology is not one of my strong suits. Did they help to increase my knowledge? Yes they did.

In this form, the GTFs acted as a sort of tutor, assisting the PTs in building a broader base of understanding relating to the subject matter content they teach. Additionally, this type of collaboration between scientists and science educators also highlights a form of collaboration encouraged in recent science reform initiatives.

The analysis of the data discussed above demonstrates that PTs working with the GTFs in this context experienced increased opportunities to enrich their understanding of subject matter content knowledge. This occurred in at least two forms, public and private. The public displays highlight for all the stakeholders involved a form of collaboration that is supported by documents dedicated to the reform of science education in America. The second form, private, served to increase opportunities for the PTs in these collaborations to enhance their understanding of the subject matter content. This increased understanding of subject matter content knowledge on the part of science teachers is also highlighted in reform documents as a necessary element in improving the scientific literacy of all Americans.

Curriculum Knowledge

PTs in these collaborations also report they benefited from increased opportunities to enhance their knowledge of the enacted curriculum found in materials and methods for instruction. Anita, an experienced middle school teacher talks about curriculum knowledge during her final interview.

> That is the other thing I think I've learned from them. There are some really simple ways to adapt things. When you're first looking at an experiment to try and you're

> thinking, "there's no way I can do this." They've [GTF] shown me that there are real simple ways to do things that are not that hard.

These comments exemplify the types of comments made by PTs regarding the manner in which these collaborations assisted them in thinking about improvement of specific lessons or materials.

Sandy, a high school Biology teacher, echoes this type of curriculum knowledge enhancement when she says,

> I've gotten some good ideas on some new exercises or well, just things that I've had ideas but just didn't have time to develop.... He's added to my exercises for my students tremendously.

Alex, a high school GTF who worked with Sandy supports this interpretation. During one of his interviews he says,

> Because she just doesn't really have as much of the knowledge in that area [DNA technology] that I have. And I think I brought some things...to the classroom that wouldn't have been done in the classroom otherwise. I think maybe I helped reinforced the importance of that.

In addition to the enhancement of specific lessons or materials, PTs also indicated that these collaborations influenced larger issues related to curriculum knowledge. For example, Anita talks specifically about her view of the subject matter she teaches when asked how this collaboration has influenced her subject matter knowledge. She states,

> I don't know that I've learned more based on subject matter, but I sure learned how to approach the subject matter in

> different ways.

Evidence to support this type of curriculum knowledge growth is found in interviews with GTFs as well as from observations of GTF and PT interactions.

Analysis of these data indicates that this type of collaboration enhanced opportunities for PTs to discuss and reflect on their curriculum knowledge. Some of these interactions dealt with the enhancement of specific lessons or materials. Other interactions focused on teaching methods and techniques for improving student understanding.

Knowledge of Learners and Their Characteristics

Analysis of the data indicates the PTs in this study experienced opportunities to grow in areas related to knowledge of learners and their characteristics. This lead PTs to reconsider their own methods and styles of teaching. For example, these opportunities influenced the way that the PTs considered students as they thought about the sequencing of material and the structuring of content delivery.

When asked about the impact of the GTF collaboration on her students, Anita discusses her own growth and how it has impacted her thinking about science.

> It's changed the way I look at science. I used to look at content first and lab second and now I look at lab first and then what content I need. So I think that is another impact for me and the students.

These comments reflect a change in teaching practice that indicates a change in belief about how students learn, that experience precedes knowledge. The intention of the change was meant to improve her students' understanding of science. This change in thinking related to her students demonstrates a better understanding of her students and how they learn science. These comments are representative of those made by other PTs focusing on students and how they best learn science. These comments were also supported by GTF interview data as well as by observations of changes in PT practice.

Additional evidence to support increased thinking about students' and how they learn on the part of PTs is found during interviews with GTFs working in other schools. For example, Lamar, a Biology GTF, discusses this when asked about opportunities to discuss teaching issues with his PT. He says,

> I think so...he's [PT] been talking about being more structured and methodical in his approach.... So I guess, just based, especially with the way Jamil [GTF] comes to class...he [PT] sort of saw what he [Jamil] was doing and the way the kids responded.

In this instance, the PT became aware of instructional techniques that were of interest to students and how the techniques improved student understanding.

In this form, working with the GTFs has directly influenced the growth that occurs in the PTs' thinking related to learners and their characteristics. These collaborations have provided the impetus for the PTs to share their dissatisfaction with their current conceptions of their students and what constitutes effective teaching of those students. This dissatisfaction with current conceptions of effective teaching is an important indicator of the possibility for change on the part of the PTs. Work on conceptual change indicates that the first step in undergoing a conceptual change is dissatisfaction with existing conceptions (Posner, Strike, Hewson, & Gerzog, 1982). This form of growth is an indicator of the potential these collaboration have for influencing future teacher development and practice.

Analysis of this data indicates evidence of PTs' growth in areas related to knowledge of learners and their characteristics. Anita decided to restructure the delivery of content, providing the experiences before the presentation of content. The PT working with Lamar and Jamil decided to reorganize his own classroom structure after witnessing the success enjoyed by his GTFs teaching in his class. Perhaps most important of all though, is the evidence that these collaborations may influence aspects of the PTs' knowledge base of teaching.

Learning Communities

Involvement in this GTF program influenced the opportunities these PTs had to participate in learning communities dedicated to improving the quality of science instruction. This involvement will be discussed in terms of three levels of participation. The first level is the level of the classroom. For the purposes of this paper this category shall be called Within Class Learning Community. In this level the PTs had opportunities to interact with knowledgeable others regarding teaching science within their own context, the individual classroom. The second level is the level beyond the individual classroom called Between Class Learning Community. In this level the PTs had opportunities to interact with knowledgeable others regarding the teaching of science beyond the individual classroom. The third level, University Level Learning Community, is the level in which PTs established contact with scientists and educators at the university level. This level includes interaction that occurred as a direct result of involvement in this GTF program as well as interaction that occurred as an indirect result of involvement in this program.

Analysis of data indicates that one of the main features of this program was the opportunity for PTs to interact with knowledgeable others regarding their own teaching practice. As mentioned above, a number of PTs indicated they had learned about their own teaching from interaction with the GTFs. Alice questioned her own personal philosophy of teaching, deciding that laboratory activities should precede the delivery of content. Matt, a PT working with Lamar and Jamil, reconsidered his own style of instructional delivery, deciding that a more structured approach might best benefit his students. Both of these changes came as a direct result of in-school collaboration between a scientist and a science educator focusing on the planning and delivery of hands-on inquiry based laboratory activities.

The GTF interviews also support the importance of these interactions with PTs as being a key element in these collaborations. When asked to give recommendations for future GTFs, Don talks about the importance of developing an interactive relationship with his PT. He says,

> I'd tell them [GTFs] to make sure they have a really solid foundation with your teacher.... There are differences in reactions and that point needs to be distilled. If you're coming from two different approaches to things, high school teacher versus researcher, one person's constantly thinking about simplifying things. The other person is trying to understand deep fundamentals of some random scientific thing.

These comments are representative of the types of comments made by several GTFs regarding the discussion of science and science teaching related issues. These discussion issues ranged in focus from the teaching of science (i.e. classroom management) to information relating to highly debated issues among the scientific community (i.e. the use and application of DNA technology). These are examples of the type of involvement in Within Class Learning Communities the PTs experienced due to participation in this GTF program.

PTs also indicated that participation in the program led to increased opportunities to interact with others regarding their own teaching practice beyond the classroom level. When asked about increased professional development opportunities, Kim states,

> I think with the whole program, I thought this summer [orientation workshop] was very beneficial....To me that was an opportunity for me to meet other teachers.... I thought that was very beneficial to me, just meeting those other science teachers.

This GTF program afforded PTs the opportunity to interact with others about their own teaching and issues related to science and the teaching of science. There are multiple types of opportunities these PTs had to become involved in learning communities focused on the teaching of science beyond the classroom level. The opportunity to meet and work with the other science teachers in the program, and the opportunities to reflect on their teaching in interviews and discussions regarding this GTF program are examples of this. In these interactions, the development of a community of learners occurred between people who worked at the classroom level, yet within differing contexts. These interactions are also representative of examples of involvement in Between Class Learning Communities that occurred as a direct result of participation in the GTF program.

Data analysis also indicated that the PTs in these collaborations established connections to University Level Learning Communities. As stated by Anita when asked about opportunities to participate in scientific learning communities,

> The other thing that has helped a lot was just working with the university. I have someone at the university I can call, even if it wasn't a GTF.... There are a lot of people out there willing to help that we just are so used to not having that we just don't even think to call.

Sandy echoes this idea. When asked about increased opportunities to participate in scientific learning communities because of her involvement with the program she states the following,

> I think so. Just because my name is out there more. The

> university has called me, and the SEPUP program, I don't think I would have gotten involved in that.

These comments exemplify typical comments made regarding increased involvement in learning communities at the university level.

PTs in these collaborations developed connections outside of the classroom due to their involvement with the GTF program. Several shared professional development opportunities that came about as a direct result of involvement in the program. Among these were opportunities to become involved in classroom video conferencing technology, science workshops, and curriculum development. Additionally, the PTs reported involvement between their classroom students and the local universities increased as a result of participation in this grant. Included in these were opportunities for students to participate in science competitions, field trips and video conferencing.

Involvement in this GTF program influenced the opportunities these PTs had to participate in scientific learning communities. This involvement occurred on three levels of participation. The first was the level within classrooms called Within Class Learning Community. In this level the PTs had opportunities to interact with knowledgeable others regarding teaching science within their own context, the individual classroom. The second level was the level beyond the individual classroom, called Between Class Learning Community. In this level the PTs had opportunities to interact with science educators working in various contexts regarding the teaching of science. The third level was the level of involvement in University Level Learning Communities. This level increased opportunities for the PTs and their students to interact with those interested in science education at the university level. This level includes interaction that occurred as a direct result of involvement in this GTF program as well as interaction that occurred as an indirect result of involvement in this program.

Conclusions

Summary

A huge investment in public funding has been dedicated to the implementation of the NSF's GK-12 programs. The NSF's investment illustrates their position that these types of collaborations are important to the improvement of science education. However, little research has been done on the impact that this type of collaboration will have on science teachers' teaching practice. Science teachers are the main vehicles by which systemic reform will be implemented. The knowledge, skills and dispositions held by the classroom teacher influences the delivery of the enacted curriculum.

This study details the impact on the science teachers in a GK-12 program; a NSF funded initiative designed to improve the quality of K-12 science teaching. PTs experienced opportunities to increase their subject matter content knowledge. This occurred both publicly and privately.

PTs in these collaborations benefited from enhanced opportunities to increase their curriculum knowledge. In one form this lead PTs to gain knowledge related to new or better methods to highlight a concept or idea.

PTs also became involved in learning communities on three levels: within classrooms, between classrooms and with the university scientific community. These categories are consistent with types of teacher knowledge identified both by Shulman and by the NBPTS.

Implications

The findings of this research highlight the need to examine in more depth three groups influenced by these collaborations, the science teachers, their students, and the scientists. This research suggests that the PTs involved in these collaborations experienced change in a number of areas related to their knowledge of teaching. Further research needs to be done which examines how sustainable these changes are. Additionally, research needs to be done which explores how these collaborations influence teacher theory and practice after the departure of the GTFs from their classrooms.

Additional studies on the GTFs and the students in these classrooms need to be implemented. This research suggests a change in PTs due to this collaboration. A logical question then becomes, how does this impact the students in these classes? Do these collaborations influence students understanding of the nature of science? Do these collaborations raise student scientific literacy so often mentioned as a goal of science education and reform minded programs?

Finally, work examining the influence of these experiences on the GTFs needs to be conducted. Recent calls for scientists to enter the classroom have come from a number of stakeholders involved in the most recent science education reform movement. Additionally, the NSF has implemented a number of programs including the GK-12 programs that place scientists in the classroom. Part of this emphasis is focused on improving scientists' relationships with, and ability to work in, K-12 schools. Work examining how successful these programs are in increasing scientists involvement in, and understanding of, K-12 science education also need to be done.

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Appendix A

Initial Formal Partner Teacher Interview Questions

1) Have you learned anything new about your subject area as a result of working with the GTF? If so, what?

2) One of the goals of the Graduate Teaching Fellows program is to increase the use of computer technology by the participating teachers, to what degree has this occurred in your situation thus far?

3) In what area(s) has the increased use of computer technology been most apparent, during instruction, for record keeping, or in some other manner?

4) Your Graduate Teaching Fellow is a member of a learning community of scientist. How has your involvement with the Graduate Teaching Fellows program impacted your communication with this learning community?

5) How has your professional development been impacted by your involvement with this program? Explain.

6) What recommendations would you make to a teacher who is considering working with a Graduate teaching Fellow next year?

7) In what ways has this program been a benefit to your students?

8) In what ways has this program been a detriment to your students?

9) Describe the students' reactions to working with a scientist.

Appendix B

Initial Formal Graduate Teaching Fellows Interview Questions

1) How has your training as a scientist prepared you for this experience as a teacher?

2) What has been the greatest obstacle or obstacles in transforming your science knowledge into an appropriate form that your students can understand?

3) Pedagogical Content Knowledge is, briefly stated, a name given for the ability of a teacher to make subject matter understandable to students. In what ways has this experienced impacted your Pedagogical Content Knowledge of science?

4) Describe how you and your cooperating teacher communicate about subject matter issues.

5) Has this program impacted you view of teaching? How?

6) What has been the biggest surprise so far regarding teaching?

7) One of the goals of the Graduate Teaching Fellows program is for the Graduate Teaching Fellows to develop an appreciation for the professionalism of teachers. Describe what impact you think this program has had on you regarding this goal.

8) What recommendations would you give to a future GTF to help her/him make the transition to a secondary science (middle or high school) classroom?

Appendix C

GTF Observation Form

Date_______________________

Grade _______________________

Subject Area___________________

Describe the content covered during class.

List the types of activities implemented during class.

Describe how computer technology was used during this class.

Describe the role of the Partner Teacher during class.

Describe the interaction between the Partner Teacher and the Graduate Teaching Fellow.

Describe the interaction between the students and the Graduate Teaching Fellow.

ELICITING PROSPECTIVE SCIENCE TEACHERS' CONCEPTIONS OF THE NATURE OF SCIENCE IN MIDDLE EAST TECHNICAL UNIVERSITY (METU), IN ANKARA.

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Many of the recent reform documents in science education in the United States, Britain and Canada emphasize that scientific literacy involves understanding both scientific concepts and the nature of science (American Association for the Advancement of Science, 1993; National Research Council, 1996; Rutherford & Ahlgren, 1990.) The main intention of these national and international documents is that understanding the nature of science is helpful to relate science, and its enterprise, to the daily life of students, teachers, researchers and science consumers as a whole society.

When we retrospectively scrutinize the science education curricula of Turkey, a country located between Eastern Europe and Western Middle East, it is apparent that Turkey followed many of the school reforms in the United States in the late sixties. Turkey imported many of the United States science education programs (e.g. BSCS, CHEMstudy, and PSSC) nearly without any detailed modification. In addition to Turkey, other countries including Canada, Australia, Israel, and Japan adopted those reform movements from the U.S. Some others, such as Malaysia and Nigeria, adopted their school curricula from Britain (Blades, 1997.) Many of these school reforms in the late sixties emphasized teaching science as content knowledge aligned with the logical positivist view of science.

New reform movements in science education emphasize that students should understand science is tentative, subject to change, and not an absolute truth of nature; but rather it is our (human) own understanding. From this point of view, new reform documents, some of which explicitly and some others implicitly, propose that logical positivist understanding of science and its enterprise is misleading. Not only reform documents, but also many science philosophers, historians, and science education researchers emphasize that logical positivist view of science is not more than a dogmatic belief or a myth (Kuhn, 1962; Lakatos 1970; Popper, 1959.)

Many of the documents related to science education school reforms address the essence of teaching the nature of science to students in science classrooms (American Association for the Advancement of Science, 1993; National Research Council, 1996; Rutherford & Ahlgren, 1990.) Science educators, researchers and curriculum specialists have been interested in teaching nature of science in addition to teaching science as a content knowledge (Bell, Lederman & Abd-El-Khalick, 2000; Blades, 1997; Deboer, 2000; Duschl, 1994; Lederman, 1992; Mathews, 1996; Turner & Sullenger, 1999.) As the allegiances of this interest, researchers and related associations define their own understandings of nature of science and propose different strategies in their teaching (Deboer, 2000.)

"What is the nature of science really?" is one of the questions many researchers pose throughout their studies. Most science educators agree that the nature of science has not been specifically defined (Lederman, 1992.) The authors predict when the "nature of science" is portrayed, the discussion will not end. Since our understanding of the nature of science includes the subjectivity and tentative characteristics of scientific knowledge and its enterprise, any probable definitions of nature of science will also be tentative and subject to change. In this respect, we are comfortable with the ambiguity of the definition of the nature of science.

Purpose

The purpose of this study is to explore the graduate and under-graduate science education students' conceptions of the nature of science, in Middle East Technical University (METU)? The sub-questions that will be helpful to illuminate the main question are:

- What do graduate and under-graduate science education students think that science is?
- What do graduate and under-graduate science education students think about the tentative characteristics of scientific theories?
- What do graduate and under-graduate science education students think about the role of experiments in scientific methodology?
- What do graduate and under-graduate science education students think about the objectivity / subjectivity and value-laden / value-free dichotomies of science?
- What do graduate and under-graduate science education students think about the role of ethics and values in science?

Theoretical Underpinnings

Blades (1997) implies that the British and American science programs that were exported to world-wide countries, present in orientation, spirit, and approach, the belief in the value of inquiry and enunciation to human progress echoed in the most ancient philosophies. The European Enlightenment era (AD. 1350-1650), through the innovations in science and art, formed this modern expressions of these orientation, spirit and approach. Blades (1997) argues that, the belief that inquiry in a rational science discipline can truly come to know objective reality and this knowledge can be used to further human progress, is the foundation of metaphysics of modernity and a modern legacy of the European Enlightenment. This belief also includes that "knowledge of the objective world is possible through reasonable, logical, experimental inquiry." Blades (1997) cites Bertrand Russel's assessment in 1952, that "one hundred fifty years of modernity have proved scientific inquiry to be an important source of economic technique capable of transforming human life."

The question posed by Turner and Sullenger (1999), "Why this belief that school science should mirror the dynamic of research science?", is thoughtful and innovative in terms of both the introspective and retrospective aspects of science. They point out that scientific thoughts are still being "equated with logical thought in general, and offered as the most effective pedagogical route, if not the only route, to inculcating clear and rational thinking." In this sense the curricular documents and the reform movements have been condemned as expressing beliefs about science, rationality, and "the mind that are as old as Bacon and Descartes".

Many of the philosophers challenged the logical positivist assumptions of science. Popper (1959), Kuhn (1962) and Lakatos (1970) mention in their essays that the logical positivist view of science is misleading. Popper (1959) discusses the falsification of scientific theories by implying that there can be no absolute correctness of any scientific knowledge. He draws attention to the fact that when we ignore the falsification of science we unconsciously demarcate science from nonscience. This leaves no space to discuss many of the serious social, political, emotional or metaphysical problems of society.

Kuhn (1962) asserted that the way that we teach science does not accurately represent the history of science. Kuhn, in his essay of "The Structure of Scientific Revolutions" retrospectively scrutinized science and its enterprise. He interrogated absolute values and deconstructed the causes of "scientific revolutions." Kuhn (1962) addressed the tentative and subjective characteristics of science by referring to "paradigm shifts" in science. When a theoretical paradigm is no longer adequate to guide understanding and research in a field, a new paradigm is developed and adapted and "paradigm shifts" occur. Previously accepted concepts and related research must be reinterpreted. Nothing may be what it seemed to be, despite being the same phenomenon that is described. A new paradigm is established, incorporating social and cultural influences of the time, and consequently, work goes on.

It is not unusual or surprising that many students and teachers think that scientific theories and claims are the absolute truths of nature. One of the reasons for this myth may be the textbooks and the way science is taught in schools. In textbooks and in science classrooms, most of the scientific theories and claims are represented as absolute truths of nature. To some extent, Kuhn deconstructed science textbooks. Kuhn (1962) claims that the aim of science textbooks is persuasive and pedagogic. When someone views science from the science textbooks, the scientific concepts become a body of knowledge, which is possessed as something valid, true, or necessary. From this point of view, the practice of science cannot be seen from the textbooks since its practice ends when someone writes the process in a textual form. What can be seen in the textbooks is what someone decides on what scientific knowledge should be. Practicing science from the texts becomes somehow impossible. Kuhn (1962) believes that education perpetuates paradigms. Students accept theories on the basis of the authority of the teacher and textbooks, not because of evidence. Applications in books are not there as proof, but because solving them is part of acquiring the paradigm at the basis of current praxis. Textbooks only show the discoveries that have led to them and nothing of the sidetracks, or of earlier, alternative paradigms. On the other hand, textbooks are essential in terms of transmitting scientific knowledge to the new generations. Textbooks, in particular, and texts related to science, in general, can be used to illustrate the past experiences of human societies on science and technology. Kuhn (1962) implicitly mentions the tentative characteristics of science by stating, "After a revolution, scientists are responding to a different world." According to Kuhn, when scientific paradigms change, the world itself changes with them. It is not the physical world changes, but our view and understanding of it changes. Even though scientists use the same instruments they had already used, and observe the same phenomenon with the same data, they can still see something new or even contradictory to their previous conceptions.

Kuhn's ideas on science and its enterprise are valuable and significant in understanding the nature of science. Being science educators, our aim should be to teach science as well as we can, and reduce the possible dogmatic assumptions and myths of science that students may construct while they are learning science from textbooks and in classrooms. Teaching the nature of science is essential to reducing the myths on science that students may construct while they are learning science.

Turner and Sullenger (1999) introduce the basic assumptions of the nature of science issues from various national and international science educational documents. Their approaches examine the extent to which they accept the nature of science. They (1999) discuss the initiatives of different associations on the aspect of the nature of science, such as the National Science Foundation, the Common Framework of Science Learning Outcomes, the National Science Education Standards, and Project 2061 Science for all Americans. They criticized these documents as having a traditional approach to the images of the nature of science. The major critique is that, these aforementioned documents significantly distinguish science from nonscientific ones (demarcation of science from nonscience.) Writers complain about the strengths of these documents in implementing the theoretical framework of scientific literacy and the nature of science in science education. For instance, the Canadian Common Framework emphasizes Science Technology and Society (STS) issues, where Project 2061, Science for all

Americans places emphasis more on technology and mathematics and the history of science. Most of these documents include some aspects of the nature of science, but they are inadequate in addressing the whole perspective of the nature of science. Turner and Sullenger (1999) pointed out that the scientific community, for instance, is portrayed as dogmatically open, cooperative, and antiauthoritarian by leaving no room to theoretical incommensurability or cultural determinism. The role of ethics and values in science is weakly addressed in many of these documents.

Longino (1990) shows how social values play a role in scientific research by illuminating the rationale of scientific reasoning. By posing the question, "to what extent science is value-free and independent of any group or individual subjective preferences," Longino defines "constitutive" values as the rules determining what scientific practice or method is acceptable. She contrasts "constitutive" values with "contextual" values, which is referred to as the social and cultural values of any group or individual preferences about what it should be. Longino agrees that social, cultural and political interests of any dominant group within the society play an important role in making scientific knowledge and its decision processes. She draws attention to the so-called external factors (i.e. racism, sexism, ideologies, and politics) in the development of knowledge. Longino exemplifies some of these external factors which she refers to as the historians' and social scientists' interests, such as Darwinian evolutionary theory and 19th century capitalism, 19th century craniometry and racism and sexism, and sociological studies detailing the connections between research and the interests of those conducting or supporting the research and of the role of science in policy making. She cites what Donna Haraway claims "science is a series of political discourses and must be read as such." Evelyn Fox Keller argued that the language of science has been constructed by an ideology of domination in individual characteristics and psychological development in personalities of modern Europe and North American societies. In scientific research, the role of social values, which can be personal, social, moral and cultural, is one of Longino's concerns. She introduces the debates about science and social values as values that produce bad reasoning. Longino (1990) claims that scientific research, and its reasoning, involve neither pure social ideologies and values nor stereotypically scientific issues of evidence and logic but both of them together as being counterparts of each other. Science cannot be labeled as good or bad science. Values of society shape the proponents of the integrity of science and so science itself is the extension of society in terms of its discourses.

There is no possibility that values will produce bad reasoning so scientific inquiry should be value-free. Science is already value and culture dependent. Hence, it can be best explained with respect to the society and its culture. Longino (1990) indicates that the view "science is a social knowledge" is not something new, but has already been accepted and advocated by Marxism previously. Ethics and values that influence science and scientific researches are the parts of the nature of science. Science educators should address the role of ethics and values in science in their science classrooms.

There is no clear definition of the nature of science according to philosophers, historians, sociologist, and science educators. Yet, there is consensus that science students and teachers should know particular aspects of the nature of science. Many of the researchers (Bell et al., 2000; Chiappetta & Felske, 2000; Deboer, 2000; Gess-Newsome, 2000, Lederman; 1992; Matthews, 1996; Staver, 2000) agree that the nature of science is a central element in the current movement to improve science education.

There is some consensus about the characteristics of the nature of science that students and teachers should understand. However, from our understanding of nature of science, there should be no limited list of the nature of science issues that one should hold. Hence, science educators should inform the students and teachers about the philosophy and history of science and let them construct their own understandings of the nature of science. According to Lederman (1992) the nature of science refers to "the values and assumptions inherent to the development of scientific knowledge." Lederman says that one's conceptions of nature of science are about her beliefs of science and its enterprise (e.g. whether science is amoral, tentative, empirically based, parsimonious, or a product of human creativity.)

The tentative characteristic of science explains that scientific knowledge is subject to change with new observations, discoveries and reinterpretations of existing observations (Schwartz et al., 2000.) Kuhn (1962) described the tentative characteristic of science by scrutinizing the paradigm shifts in the history of science. Empirical characteristics of science explain that scientific theories and claims originate from observations of natural world (Schwartz et al. 2000.) The nature of science issues also include that science is a human endeavor influenced by the culture in which it is practiced. So, different cultures may view the same phenomena but interpret them differently. Multiple perspectives may contribute multiple interpretations. Ethics, values, agendas, and prior experiences of cultures and/or scientists influence the development of posed questions, hypothesis, data collection procedures, and its interpretations. This characteristic is referred as the subjectivity aspect of science (Schwartz et al., 2000.)

Cummins (2000) advocates that in science education programs, we need to address prospective science teachers' conceptions of the nature of science in order to reach our goals of science literacy about the nature of science in K-12 students. In this study science education students' conceptions in Middle East Technical University (METU), in Ankara, had been studied.

Methods

Participants in Study

There are several reasons why researchers have interested in exploring Turkish students' conceptions of nature of science. One of the reasons is the same interest with the literature that prospective science teachers conceptions are vital in achieving contemporary reform movements related to nature of science issues. In order to augment the science education programs all around the world in general, and in METU in particular, students' conceptions of nature of science are need to be illuminated so that any compulsory action can be taken. Another reason why we selected the students in METU is science education students' conceptions in developing nations under the influence of modernism are rarely considered in the literature. Turkey has not only been importing the educational reforms from USA since 1960's but also many of the ideologies that aligned to modernism since the country had been established in 1923. The findings of this study will illuminate what the students' conceptions of nature of science look like in a developing nation and give sights to the potential implementations of science education programs in colleges of educations.

The participants of this study include 25 undergraduate and graduate science education students enrolled in the Science Education Program in METU, in Ankara. Students who graduate from the Science Education department will most likely teach high school science in grades 8 to 11. The graduate students in science education department represent another faction of the science education teacher population in Turkey. The medium of education in METU is in

English and the teachers graduated from the science education department are prepared to teach science in both English and Turkish.

Students who enroll in this department generally have science and mathematics related programs in their high school years. These science education undergraduate students take several science courses in their first three years of program of studies. Graduate science education students have more extensive experiences in science classes when compared to undergraduate students.

Instrument

A questionnaire, which had been adapted from previous studies (e.g. Schwartz, Lederman & Crawford, 2000), was used in this study. The questionnaire was modified by examining previously administered tests, surveys and questionnaires found in literature (i.e. Cummins, 2000; Lawson, 2000; Schwartz et al., 2000; Smith, 2000.) Several experts in the science education research field discussed the items for the validity issues of the questionnaire. The questionnaire is in English.

The questionnaire was designed in such a way that the open-ended items would address respondents' understandings and thinking on the "tentative", "empirically based", "subjective" and "value-laden" characteristics of science and its enterprise. The questionnaire assesses 4 sub-dimensions such as the students' conceptions on "science in general"; "tentative characteristics of the nature of science"; "scientific methodology" and "the role of ethics and values in science." The actual questionnaire used in the study is represented in the Appendix to the paper.

What science is and what distinguishes scientific thinking from other disciplines of inquiry is one of the most important aspects of the nature of science (Deboer, 2000.) The first six questions aim to explore what the participants think about science and how scientific methodology differentiates itself from other form of inquiries. The last two questions are designed to illuminate what the participants think about the subjective and value-laden characteristics of science.

Sampling Strategies, Typical Access, Data Collection

In order to connect with participants of this study, the first author visited METU in December 2000. Specifically, being a student in the science education department was the master criterieon for the participants of the study. For the undergraduate group of the students, the questionnaire was administrated in a class in METU by that researcher. The confidentiality of the data collection process, and participants' rights were explained before the administration of the questionnaire. Participants were informed that their participation were voluntarily and confidential. All of the students in the classroom voluntarily participated in taking the questionnaire. Respondents had been informed that they could respond either in English or Turkish whichever language they felt comfortable in expressing their conceptions. The time period given to the students to complete the questionnaire was unlimited. The approximate time for the participants to complete the test was recorded as 40 minutes. The graduate science education students who agreed to participate in the study completed the questionnaire individually.

Data Analysis and Storage

Undergraduate and graduate science education students' conceptions of the nature of science were analyzed using an inductive approach (Erickson, 1986) to find common themes across the participants written responses. Participants' responses to an open-ended Nature of Science Questionnaire were analyzed, and the possible meanings that they mentioned were pointed out.

Most of the participants' responses were in English. The few responses written in Turkish were translated by the first author. Participants' responses were stored in an electronic database (Microsoft Access). The advantage of storing the data in database software was, researchers could easily access and interpret each participant's responses as well as all participants responses on a particular item. Participants' responses had been read by the researchers, and categorized through the readings. Researchers coded these responses. The coding process was an ongoing process in which emerging codes were interrelated with the predetermined codes.

This study was a within-case study type in which the conceptions were considered as being unique, rather than the individuals. It was a concept-based (where the phenomena studied or the concepts explored are essential) rather than a subject-based (where participants or their unique experiences are essential) study. The concepts that the participants hold and the distributions of the subject according to their conceptions were critical to the researchers.

Findings

In this section, the authors describe the categorizations and summarize the students' responses to each of the items of the questionnaire. A number from 1 to 25 has been given to each administrated questionnaires, and each participant is represented by that number. P#x refers to the participant where x represents that particular respondent. Students' responses are also being represented by graphs in the subsequent section.

What is science?

The first question of the questionnaire was; "What, in your opinion, is science? What makes science (or a scientific discipline such as physics, biology etc.) different from other disciplines of inquiry (e.g. religion, philosophy)?" (See Appendix). Twenty-four of the students responded to this item. Two of the responses were found meaningless to be categorized. Totally 22 responses were categorized.

The majority of the students stated that science has a structured methodology for its practitioners to follow. 45% of the (10 responses out of 22) meaningful responses indicate that science has a "methodology." Some examples of this categorization are given below:

> Science requires some hypothesis, experiments and reaching conclusion (p#7.)
>
> In science, scientific knowledge is proved by experiments, and it depends on observations, measurements and science is the result of wonder. It is open to new developments and it includes some procedures like making hypothesis, observing, gathering data, making experiments, concluding, etc (p#8.)

One of those students responded that the main discrepancy of science from other disciplines is the methodology it follows. This student responded as:

> ....The main difference between science and other disciplines is that making science requires following a scientific method in an organized manner (p#20.)

Six students (27%) indicated that science is an inquiry searching for absolute truth (in nature). This perspective is consistent with the logical positivist view of science. The following quotes illustrate some of the students' responses.

> In my opinion, science is truth, with science, you can prove everything; evolution, electricity, water and all other things, living or non-living. This is the difference between the science and religion for example (p#16.)

> Bilim dogrulugu kanitlanabilir ve her insan icin belli kesin sonuclari olan ve sonuclari kisiden kisiye degismeyendir. Diger disiplinler (e.g. religion, philosophy) lerden ayiran en onemli ozelligi bence sonuclari veya nedenleri her kisi tarafindan farkli yorumlanamamasidir. Yani kisiden kisiye farklilik gostermez, biyoloji, fizik gibi bilimler. Translation: Science is something that its truth can be proven, have obvious certain results for everyone and not subject to change. The main difference of science from other disciplines (e.g. religion, philosophy) is that its conclusions and consequences won't be interpreted different with every other. In other words, the disciplines for instance biology and physics aren't subject to change (p#19.)
>
> In my opinion, in universe there is an explanation of everything. Science tries to find out "true" explanation by a "systematic approach". And science is the result of human curiosity, it is just like a game, but it is not easy to determine whether we've won this game (p#22.)
>
> Science can be defined as the observation of events in order to discover facts about them and formulate principles or laws according to these facts. Actually, it is the body of knowledge, which is derived from observations and experiments. Science does not change according to people. It is unique all over the world. Science can be proven at any time (p#24.)

Three of the students (14%) thought that science is the explanation of nature. The following response is an example of this categorization.

> Science is the explanation of what is going on in nature, what is the reason of some events occurring, and how livings behave in several conditions (p#23.)

Two of the students (9%) indicated that science is germane to progress. The following responses are taken from these students' responses.

> Everything [science] that makes us improved (p#18.)
>
> … it [science] is built with all help of peoples, everyone makes progress, the other one continues… (p#3.)

One of the students (4%) mentioned that science is a bridge between society and technology. This view is parallel to Science, Technology and Society perspective. Her response is represented below.

> Science is a bridge between society and technology, which makes human life easier. Science is different from other disciplines because its product is less negotiable than others. Unless there is a new theory or fact, old ones can be accepted. Facts can be changed with new ones that are obtained with controlled experiments, however in philosophy there is no experiment. In religion, facts can not be changed (p#21.)

The analysis for this item indicates that majority of the students hold similar conceptions with what logical positivist view of science implies for science. Most of the responses represent that students view science as a structured methodology that can come to know objective reality (and/or absolute truth). In addition to that, the scientific knowledge is generally associated with a linear progress. Only one of the participants implied a different perspective than the logical positivist view of science.

What is an Experiment?

The second question was: "What is an experiment?" (See Appendix). Eight responses out of 22 meaningful responses (36%) were categorized as "experiment is proving scientific knowledge." The following example represents one of those students' conceptions.

> Experiment is a way to prove the scientific fact, or is a way to reach a scientific fact (p#9.)

Five students (23%) responded that experiment is a kind of "tool" or a "methodology." Below, there are some of the example responses for this categorization.

> It [experiment] is a tool for understanding of science subject, and prove the hypothesis in science (p#7.)
>
> Experiment is a way of problem solving and a way to answer any scientific problem (p#20.)
>
> In fact it is a tool which helps us to understand whatever we are trying to understand. It gives examples from life. It just gives a simple explanation for complex happenings, sometimes it is a way of verification some happenings (p#23.)

Four students (18%) mentioned that experiment is "testing hypothesis". The following responses exemplify this categorization.

> Experiment is testing a hypothesis and drawing a conclusion (p#25.)
>
> It is a way to proof or disproof the hypothesis (p#21.)
>
> [Experiment] a way to check whether the explanation we proposed for a certain phenomenon can be verified (p#22.)

> An experiment is a trial or definite observation which is made to prove or disprove some idea. Aims of the experiment can be different; for example, it can be done to discover, to test or to show or illustrate something (p#24.)

The majority of students thought that "experiment" is proving scientific knowledge in an organized, structured manner.

Does The Development Of Scientific Knowledge Require Experiments?

The third question was: "Does the development of scientific knowledge require experiments? Yes ____ No ____, Please explain your response. Include one or more examples to justify your positions" (See Appendix).

All of the students responded positively to that question. Their explanations are various. Twenty-two of the participants out of 25 responded that item. Eleven students (50%) strongly implied in their open-ended responses that experiment is a requirement for scientific knowledge. The following responses represent this categorization.

> I think, it is necessary to do experiments in order to develop scientific knowledge. Experiments make the ideas concrete and visible to everyone, and they also make things clear in mind. Repetition of them gives us the chance of see and understand event whenever we want. Without an experiments, we cannot construct true and acceptable knowledge one over the other (p#24.)
>
> … go in theory is only possible with experimental agreement. It is like a finding a way in dark, by theory without experiment" (p#3.)

> Without doing any experiment, it is impossible to support or reject any hypothesis about any scientific knowledge (p#20.)
>
> Without making observation, carrying out experiments, it is not possible to test our explanation, predictions (p#22.)

Four students (18%) implied that the reason of experimenting is to "theorize the scientific knowledge." The example responses are given below.

> Yes because in order to reach conclusion and make theory (p#7.)
>
> To prove the answer that we found for our questions, and to investigate if our hypothesis are true or not (p#14.)

Three students (14%) also mentioned experiment as a "tool' in their responses. Such as:

> Scientific knowledge means that people agree with results that is obtained with experiments. Therefore, we can say that experiments are tools to reach scientific knowledge (p#21.)

The majority of students thought that an experiment was a requirement to reach valid, meaningful scientific knowledge.

Does a Theory Ever Change?

The question four includes four sub-items within itself. The first item was: "After scientists have developed a scientific theory (e.g. atomic theory, evolution theory, light theory), does the theory ever change? Please explain your response. Include one or more examples to justify your positions" (See Appendix.)

Twenthy-two students (88%) responded affirmatively to the question. Three students (12%) answered "No" to the question. Six students' explanations were meaningless to be categorized. 15 students' (71%) responses imply that scientific theories are subject to change. The example responses are represented below.

> Teoriler degisebilir" Translation: "Theories are subject to change (p#1.)
>
> A new kind of theories is proposed. There is no unique theory to explain all properties of light, atoms, every theory is projected one point. This means there is a possibility for the new ones (p#3.)
>
> Theories can be considered as temporary knowledge. If theories are proved in different positions and in different situation, theories can be laws. If not theories can be changed (p#21.)

Four students (19%) mentioned in their responses that the change in theories is progressive. Such as:

> Technology is developing. So a change in theory can be seen. A change theory in positive side (p#4.)

One of the 3 students (14%), who responded negatively to the question, explained her response as:

> No, In fact the theories doesn't change as far as I know, but other theories are proposed by different people and new theories completes old ones (p#23.)

The majority of the students thought that theories are subject to change. Even though it was not explicitly asked, some of the students implied in their responses that the changes in theories are progressive.

The second subsequent item was: "How is the theory established and justified?" (See Appendix.) Seven students didn't answer this question. Eleven students' (61%) responses indicate that a theory is established and justified through experimenting. The following responses exemplify those responses.

> By collecting data and doing experiments… (p#14.)
>
> A theory is established and justified when all new data obtained or all new experiments done over a long period of time support it (p#20.)
>
> After many observations and experiments theories can be established (p#21.)

Two students' responses (11%) were parallel to Popper's falsibility idea (Popper, 1959). Such as:

> Theory is a generalization of knowledge. It does not require to justify, until it is to be unjustified (p#11.)
>
> If the result of observations, experiments are consistent with theory then we can say that we fail to reject that theory however it is not so possible to say that this theory is absolutely true (p#22.)

One student (5%) responded that she doesn't know the answer. Her response was:

> "I don't know" (p#23.)

The majority of students thought that a theory is established and justified through experimenting.

The third subsequent item was: "Explain on what basis theories can be changed?" 10 students didn't answer this item. 4 students (26%) mentioned the role of new theory. Such as:

> A theory can be changed on the basis of new findings, new data and the results of experiments done (p#20.)

> By new views, predictions based on accumulated knowledge through observations, experiments and logic (p#22.)

Three students' responses (20%) were parallel to Kuhn's paradigm shift perspective. Such as:

> A new, better explained theory can change the old one (p#16.)

One student (6%) mentioned that she doesn't know.

> ... I don't know (p#23.)

Students' responses to this item are not adequate to have a generalization. On the other hand, the majority of meaningful responses mentioned that new theory was the first criteria for a theory to change.

The fourth sub-item was: "Explain why teachers bother to teach scientific theories. Defend your answer with specific examples" (See Appendix). Fourteen students' responses were found meaningful to this item. Five students didn't answer this item. Four students (28%) mentioned that the subjectivity of theories is the reason why teachers bother to teach scientific theories. The following example responses represent this trend.

> Teachers bother to teach scientific theories because they are not completely true. Different views exist about a specific theory. These views can contradict with each other which may lead conflict in student's mind about the scientific knowledge (p#23.)
>
> Because theories are not exactly true, but on the other hand theories are not false either. For example evolution theory some of the scientists believe that this theory is true, some of them don't believe that. In this theory, some of the situations are not explained yet (p#21.)

> Because they [theories] are subject to change, there're conflicting views, without a deep understanding discussions on these theories in the classroom may lead to confusion, e.g. evolution (p#22.)
>
> Maybe it is difficult to defend a scientific theory. There may be conflict between any students' idea and the theory and teacher cannot say your idea is wrong. Teachers like to teach laws since it is unique; it cannot be changed, etc (p#24.)

Two students (14%) thought that the reason was because of students' lack of scientific knowledge. Such as:

> To explain every aspect of theory is difficult, they [students] don't have enough background, to believe its correctness and not change is easy, to say why it cannot be is difficult. For a making compound with noble gases are seems to be impossible, everyone said they are stable, but X changes their mind, only the full orbital cannot explain the making compound for all elements (p#3.)

Two students (14%) thought that this was because of teachers' attempts to teach theoretical scientific knowledge rather than the practical. Such as:

> Because they [teachers] try to teach science only theoretical base, not practical or daily life (p#9.)

Three students (21%) believed that teachers do not bother to teach theories. Such as:

> No, I do not bother to teach scientific theories but some teacher may, may be they couldn't understand the theories accurately (p#11.)

It is difficult to generalize student's responses for this item.

Difference between a Scientific Theory and a Scientific Law

The fifth item was: "Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example." Fourteen students (56%) thought that theories are subject to change, but laws are more consistent and not subject to change. The following responses are some of the examples of those students' responses.

> Of course, theory can be change, it is not unchangeable, but laws are not changed, they are true everywhere (p#3.)
>
> Scientific law cannot be changed but, theory can be changed (p#16.)
>
> Scientific theory can change, a scientific law cannot change (p#7.)
>
> Of course, theory can be argued, some scientists may not agree with a theory but law is a fact cannot be argued (p#9.)
>
> Yes, scientific theory opens to any changes but scientific law doesn't change. It's acceptable for all humans (p#12.)
>
> Theory can be changed. Law does not change. Newton's Law: $F=ma$, Einstein's theory: $E=mc^2$ (p#14.)

One student (4%) thought that there is no difference:

> No, because theories are recognized as laws (p#15.)

One student (4%) wrote that she doesn't have any idea:

> I don't know (p#5.)

One student described her position in detail:

> There is a difference between a scientific theory and a specific law. Theories are supported repeatedly with new data and experiments but still

> there is a possibility of changing. When a theory is sufficiently tested and validated, it becomes a law and it is much more difficult to reject it (p#17.)

The majority of students thought that laws do not change, but theories do.

Scientific Theories

The sixth item has three dimensions. These dimensions can be seen in the Appendix A. The main question was: "According to your field of study and interest, select one or more of the following three items, and answer them."

Nine of the respondents out of 14 meaningful responses (64%) re-represented the scientific explanation of the situations mentioned in the questions. Such as;

> They [scientists] use evolutionary characteristics. Biochemical characteristics, Genetic characteristics, Genetic characteristics, Ecological characteristics. Make studies on these criteria and decide what a species is (p#7.)
>
> Interbreeding, fertile offspring, their similar characteristics (p#10.)
>
> Scientists can determine the use of species by looking at their features similar or not similar. And their responses to for why scientist selects one species. They select one that reproduce more rapid than other (p#12.)
>
> With the help of electronic microscope (p#4.)
>
> By doing experiment, for example Rutherford's experiment (p#5.)

One student thought that;

> They defined species in the best way it could be (p#15.)

Two of the students (14%) mentioned that scientists take a reference point and built their arguments. Such as:

> … do to something we should start with somewhere (p#22.)

Is Science Completely Objective and Value Free?

The seventh item was: "Is science completely objective and value free? Why or why not?" (See Appendix.)

Twenty-one students responded to that item. Fifteen students (71%) thought science is (or should be) objective. Some examples of these responses are represented below.

> It [science] is objective since it is based on facts. Value judgments can not be used in reaching scientific knowledge (p#25.)
>
> Yes, completely objective, it [science] can not change person to person (p#6.)
>
> I think it [science] should be completely objective and value free because it is the comment of unive-rse, reality shouldn't be changed by scientists (p#11.)
>
> It [science] should be objective but the scientist' attitudes, beliefs, ideologies affect it. But the real science is objective (p#9.)
>
> Natural sciences should be completely objective and value-free. It should be independent of the person. Otherwise it can not be science; it can only be a fact of persons. Feelings, values should be far away from the science. But for social sciences, it can be more flexible. Since, for social science, there is no empirical evidence it can be more subjective than natural science (p#24.)

Even though, some of these students thought that science is not completely objective, they still believed that science should be objective. This belief that scientific practice should be objective was common for most of the participants. The following example illustrates that kind of thinking.

> I don't really think that science is completely objective. It is possible that scientists design experiments and test their hypothesis according to the expected results. But, the science should not be like that. It is not always possible to reach the predicted or desired results in science. Also scientists are influenced by some other factors such as religious, cultural, ethical and social factors. These also lead science to be lack of full objectivity (p#20.)

6 students (29%) thought that science is not objective. A sample respond to this is as;

> I don't think so. Since the people find it [science], there are always subjective points. May be in nature the pure science can be found but not people are finding (p#3.)

Societal, Cultural and Personal Beliefs

The eight and the last item was: "Are scientists influenced by societal, cultural, and personal beliefs and ways of viewing the world? Yes ____ No ____ Please explain your response. Include one or more examples to justify your positions" (See Appendix.)

Twenty of the responses (91%) to the above yes-no item were affirmative. Only two participants (9%) responded that "scientists are not influenced by societal, cultural, and personal beliefs and ways of viewing the world." When their explanations were analyzed, it can be said that seven of the students out of 16 of them who wrote an explanation (44%) think the influence of societal, cultural, and personal beliefs and ways of viewing the world is on what the scientists study. None of them indicated that this influence can be on the scientific knowledge. Some of the examples are illustrated below.

> Scientists from different cultures see the world different from each other. This affects their study on a problem. For example, Turkish and Japan scientists' view about earthquake may be different (p#25.)
>
> Of course, they influenced by societal, cultural and personal beliefs. These create a point of view for scientists, or may be a starting point of study. But at the end, scientific law or theory should be clear from these subjective effects (p#24.)

Four (25%) of the students mentioned the influence of ethics, history, ideology and religion on the scientists practices. For instance:

> If a scientist does not believe in God, he tries to prove evolution, but if he or she believes in God, will try to prove the creation and reject evolution (p#9.)

2 of the students (12%) thought that scientists are influenced merely because they were human, and this was the nature of being human.

Graphical Representation of Categorizations

In this part, participants' responses are represented graphically. For each of the sub-questions, the related categorizations and the number of the responses have been drawn.

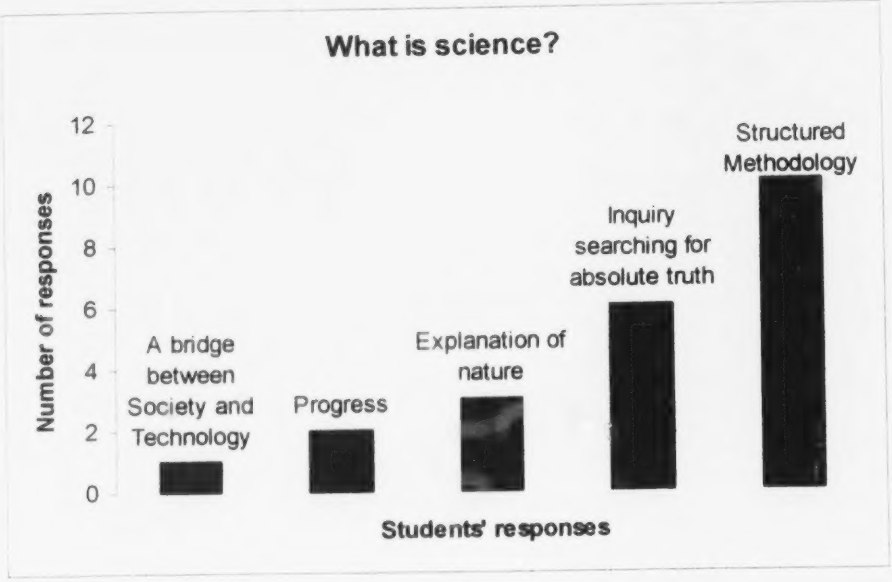

Figure 1. What do graduate and under-graduate science education students think that science is? (These categorizations are based on the students' responses to the 1st item of the questionnaire.)

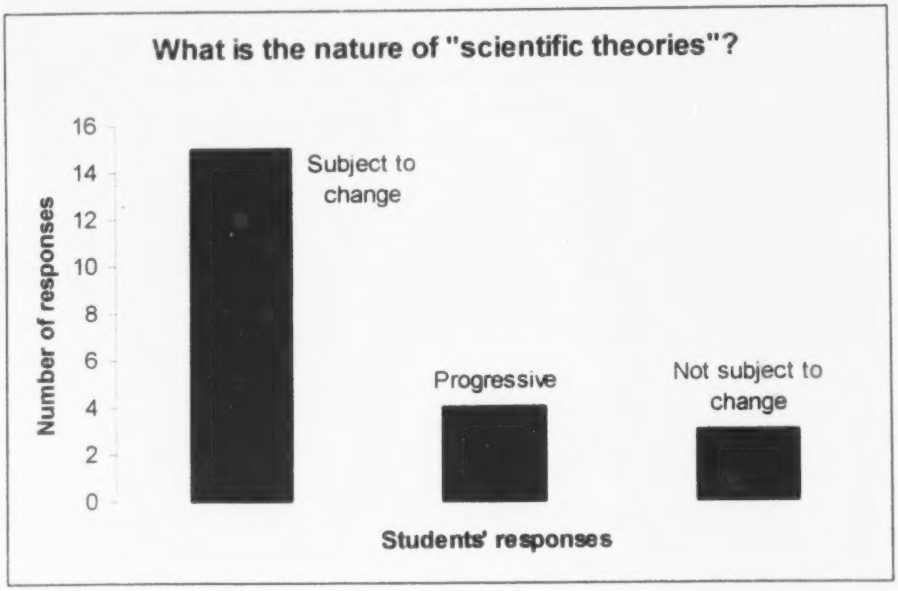

Figure 2. What do graduate and under-graduate science education students think about the tentative characteristics of scientific theories? (These categorizations are based on the students' responses to the 4th, 5th and 6th items.)

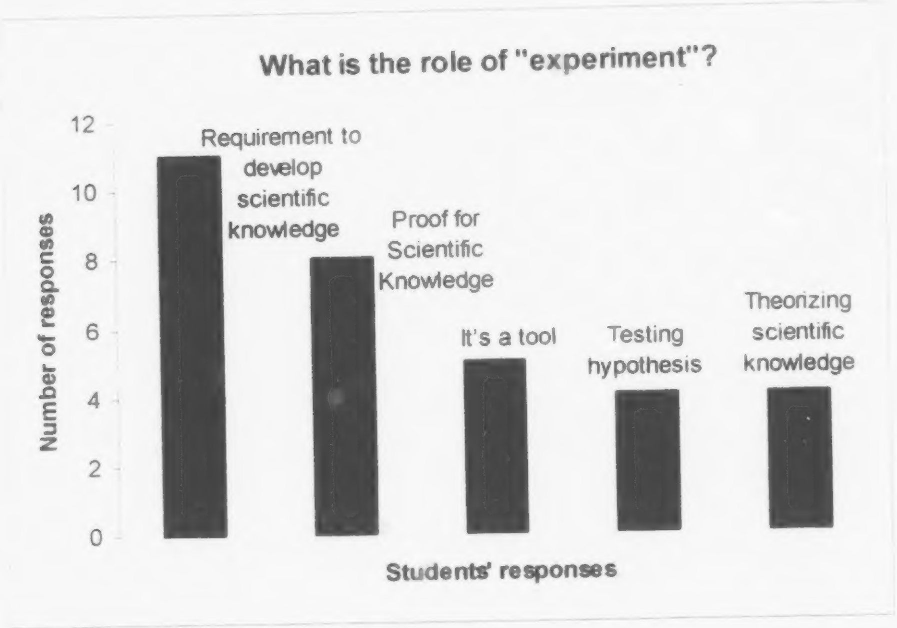

Figure 3. What do graduate and under-graduate science education students think about the role of experiment in scientific methodology? (These categorizations are based on the students' responses to the 2nd and 3rd items.)

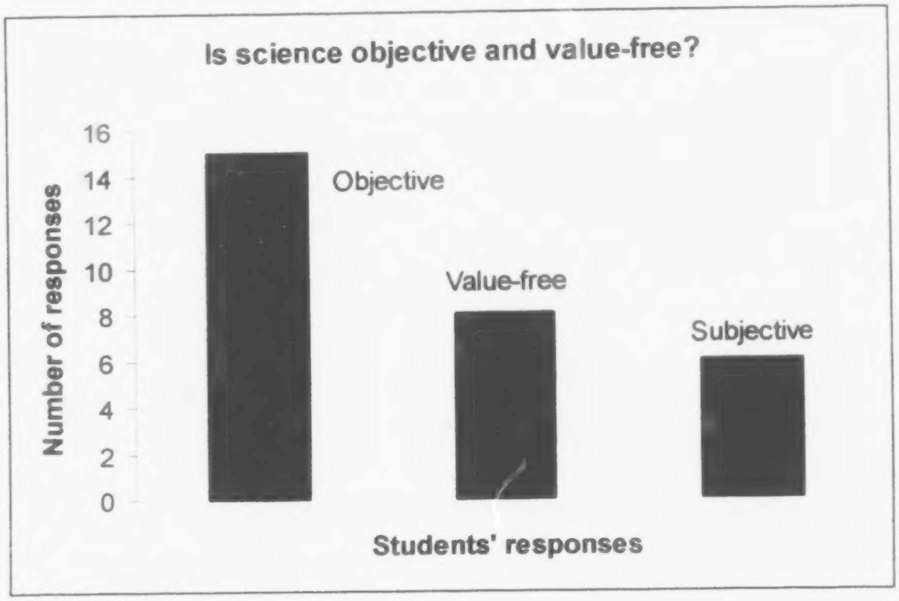

Figure 4. What do graduate and under-graduate science education students think about the objectivity / subjectivity and value-laden / value-free dichotomies of science? (These categorizations are based on the students' responses to the 7th and 8th items.)

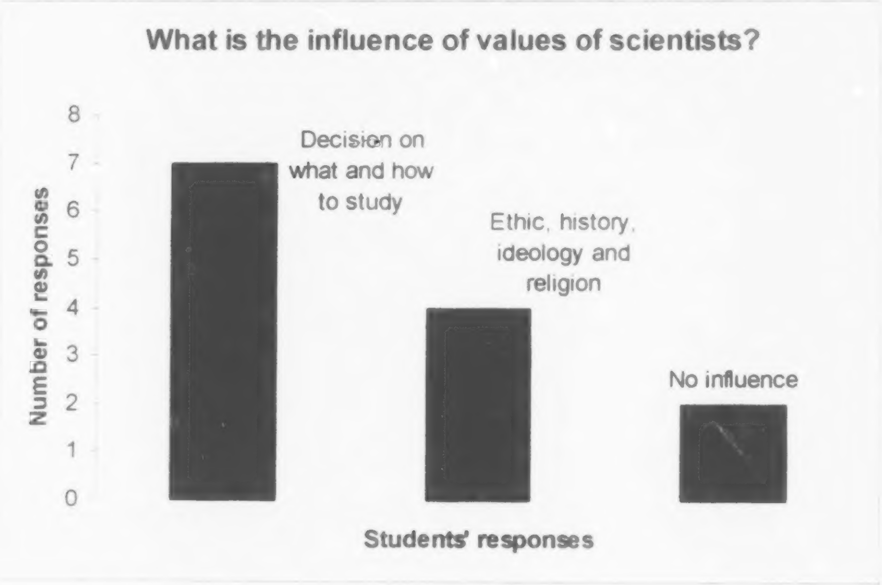

Figure 5. What do graduate and under-graduate science education students think about the role of ethics and values in science? (These categorizations are based on the students' responses to the 8th item.)

Discussion and Implications

Findings of this study suggest that the majority of the participants hold views of nature of science aligned with logical positivism. Science was perceived mostly as structured and logical, and if not the only, the best way of searching the truth of nature. Scientific experiments were thought a requirement for development of scientific knowledge. That strong argument scientific experiments are required to develop scientific knowledge may be the consequence of how scientific methodology and experimenting are portrayed as a step-by-step process by most of the science textbooks and related materials (Cummins 2000.) Students should be informed about the multiplicity of methods in constructing scientific knowledge so they may have an appreciation that science is not merely a structured and logical methodology: "doing experiment and confined to laboratories" (American Association for the Advancement of Science, 1993.)

More than half of the Turkish students (71%) thought theories are subject to change. Even though it was not posed explicitly, most of them implied in their responses that this change is progressive and hopefully achieves a thorough understanding of natural phenomena. Almost half of them indicated that there is a possibility in the future science will find *all* the answers it asks. This is an interesting finding of this study that should be taken into consideration. Can this be the reason why most of the students think science is, at least should be, completely objective, value-free and always associated with being the only ideal decision making process?

Whether science is progressive or not is open to debate from the different standpoints of philosophies of science. In science, new paradigms come into being when the previously accepted paradigm is no longer valuable in explaining the particular phenomenon. Kuhn (1962) argued that newly accepted scientific paradigm as well as the theories can not be perceived as better and/or progressive than the previous ones. This characteristic was named as incommensurability of scientific paradigms where the comparison of the consequent paradigms is hard to achieve. Incommensurability also accepts that there is no absolute truth that an individual can achieve. From this point of view, explicit knowledge assumption is inapt. Thus a linear progression in science becomes a dogmatic assumption. Scientists will choose the most appropriate theory within the possible options, according to their values. Kuhn (1962) mentioned that this choice is generally based on the logical and methodological codification rather than a matter of psychological description. Though, logical and methodological procedure still does not stipulate a linear progression toward an absolute truth of nature. Denying the existence of absolute truth of nature (explicit knowledge assumption) is rarely addressed in researches related to nature of science issues. This emerging finding of this study inspired us to hypothesize a relationship between the students' appreciation of absolute truth of nature (explicit knowledge assumption) and their views of nature of science aligned with logical positivism.

Most of the students thought that laws do not change, but theories do. The misconception that theories turn to be laws by the succeeding experiences is held by many of the participants of this study. Students were not aware that many of the scientific explanations and classifications are human constructions. Many of them also thought that science was objective. If science were not objective, then it would not be "good science". Good science is valued by what extent the scientific explanation behind it was objective. Students thought that the ethics and values of science are associated with objectivity of science. The role of ethics and values in science were not meaningfully understood by the students. The role of ethics and values entering into and exported from science and technology should be addressed in science education (Yalvac, 2001.)

The limitations of this study include one method of assessment (Open-ended NOS questionnaire, see Appendix), and a particular population of students in METU (24 undergraduate and graduate students). Data was solely collected through an open-ended nature of science questionnaire which may not be sufficient to gather detailed robust information (Lederman, 2000). For instance, in depth interview sessions would give more insight into the students' conceptions of nature of science.

Graduate and undergraduate students' conceptions could be compared, so that similar or different patterns can be investigated. The factors that might affect students' conceptions of the nature of science can be explored with more detailed studies.

Conclusion

This study shows that most of the Turkish graduate and undergraduate science education students view science and its enterprise aligned with logical positivism. We propose that the nature of science issues should be addressed more specifically and/or explicitly in science education programs in general, and in METU in particular. Students should be informed about the multiple philosophical, historical, sociological and cultural perspectives on science and its' enterprise. An STS education can be a way to initiate that kind of discussion (Blades, 1997). Obviously that kind of education include discussions related to the multiple philosophical, historical, sociological and cultural perspectives on science and its' enterprise to the classroom. How the participants differentiate the concepts of science and technology and its relation with society was not explored in this study. When students' views on the interactions of science, technology and society (including the roles of ethics and values entering into and exported from science and technology) are investigated and added to the findings of this study, there will be more sufficient information in helping to design future science education programs.

It is essential here to mention that we do not campaign all students should necessarily hold similar conceptions, but we suggest that students should have multiple, at least not one, perspectives of the nature of science. We agree on this merely because of the very nature of the nature of science. If we deny the existence of absolute knowledge (explicit knowledge) assumption, then why should one expect the nature of science should be an explicit definition?

Appendix: The Nature of Science Questionnaire

1- What, in your opinion, is science? What makes science (or a scientific discipline such as physics, biology etc.) different from other disciplines of inquiry (e.g. religion, philosophy)?

2- What is an experiment?

3- Does the development of scientific knowledge require experiments?

Yes _____ No ______

- Please explain your response. Include one or more examples to justify your positions.

3- After scientists have developed a scientific theory (e.g. atomic theory, evolution theory, light theory), does the theory ever change?

- Please explain your response. Include one or more examples to justify your positions.
- How is the theory established and justified?
- Explain on what basis theories can be changed?
- Explain why teachers bother to teach scientific theories. Defend your answer with specific examples.

4- Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

5- According to your field of study and interest, select one or more of the following three items, and answer them.

- Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

- Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a specious is?

- Science textbooks often represents that the nature of light is explained by two different theories: particle theory and wave theory of light. Particle theory of light assumes that photons (light) are like particles. Wave theory of light assumes that photons are like waves. How certain are scientists about the nature of light (photons)? What specific evidence do you think scientists used to determine what a photon is?

6- Is science completely objective and value free? Why or why not?

7- Are scientists influenced by societal, cultural, and personal beliefs and ways of viewing the world?

Yes _____ No ______

- Please explain your response. Include one or more examples to justify your positions.

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THE ELEMENTARY SCIENCE TEACHER AS RESEARCHER

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Amy Roth McDuffie, Washington State University

Overview

Elementary teachers are usually generalists, without specialty or special preparation in either science content or pedagogy. It can reasonably be argued that their primary role is to prepare their students to be literate adults, and thus, many are literacy specialists. Oftentimes elementary teachers may lack confidence in teaching science (Cox & Carpenter, 1989; Perkes, 1975; Tilgner, 1990) and thus avoid science because it is not their specialty (Atwater, Gardener, & Kight, 1991; Schoeneberger & Russell, 1986). Most elementary teachers have never conducted a scientific inquiry, yet they are being asked to teach science as inquiry (Kielborn & Gilmer, 1999). Even elementary teachers who are confident in their science backgrounds and teaching approaches could benefit from conducting an inquiry project, and could improve their teaching practice with systematic study. Though an action research project is not the same as a scientific inquiry, it can still provide an experience similar to scientific inquiry for the teachers. Thus, an appropriate strategy for fulfilling both a need to engage in inquiry, and a need for professional development in science teaching would be to prepare teachers to use action, or teacher research, in their teaching practice.

Inquiry

The *National Science Education Standards* (NRC, 1996, 2000) recommend that all science teachers continue to develop their pedagogy and content knowledge through inquiry. Inquiry is defined as raising an investigable question, developing methods to answer that question, carrying out those methods, analyzing the data, and reporting findings and making conclusions. It has been traditionally thought of as difficult to prepare elementary teachers to use inquiry methods to teach science, partially because they may have limited science backgrounds, and likely no experience in conducting scientific inquiry (Kielborn & Gilmer, 1999).

Giving K-8 teachers experiences with scientific inquiry has been shown to improve their understandings of inquiry, hopefully relating to their abilities to teach using inquiry to their own students (Kielborn & Gilmer, 1999). Additionally, learning in context is important, (Putnam & Borko, 2000; Saxe, 1988), and thus, using research on one's own teaching can provide a personal context for inquiry.

Teacher Development

There have been recommendations to support elementary teachers in professional development for both pedagogy and content for teaching science (National Commission on Science and Mathematics Teaching for the 21st Century [The Glenn Commission Report], 2000; NRC, 1996). Oftentimes teachers receive materials or textbooks to use for science instruction, but no guidance in their effective use. Just getting materials does not guarantee an improvement in teaching. Rather, it is the professional development that helps teachers effectively use the materials that can create an improvement in teaching. However, not all curricula, materials, or strategies are equally effective for all teachers, grade levels, and student groups. What can teachers do to improve their own science teaching in their teaching setting? One appropriate strategy is for teachers to conduct action research projects to actually test a teaching strategy, materials, or curricula, with their students, to track the effectiveness of the strategy. The action research project allows the teachers to note under which circumstances and with which students a new strategy is most effective. It enables the teachers to have data supported reasons for using particular strategies, and it shows the teachers, through the data and evidence collected, how effective new strategies can be for student learning. Teachers can make changes in their own teaching, and use data to support the implementation of those changes.

Teacher Research

What is teacher, or action, research? Simply put, it is when the classroom teacher conducts research on her own teaching or teaching situation. Feldman and Minstrell (2000) describe action research as teachers inquiring into their teaching in their classrooms. The teacher systematically designs a study, collects data, analyzes the data, and interprets and reports the results, a process that parallels scientific inquiry. In fact, it can be defined as inquiry into one's own teaching. The study can be used to inform teaching practice, and develops a reflective practitioner (Hubbard & Power, 1993). One of our preservice teachers aptly summarized her understanding of action research based on her experiences:

> You are doing something [in the classroom] and then you are asking yourself "Does this really work?" And you are not relying on intuition to say, "Well, it felt like it kind of worked." You're actually looking for evidence to say "Does this work?"...So, [in action research] you are going a step further than just a visual kind of thing, an emotional kind of thing, you are looking for evidence.

Schon (1983) recommends that practitioners in any field become reflective to be aware of, and to improve their practice. Indeed, in teacher education with the emergence of programs based on a constructivist perspective for learning, a central goal of many programs has been developing reflective practitioners (Christensen, 1996; McIntyre, Byrd, & Fox, 1996). Through reflection teachers have the opportunity to build their own knowledge about their practice from their own experiences. It has been shown that classroom-based action research promotes reflection on action for preservice teachers (Valli, 2000). Elementary teachers can become more reflective of their science teaching and base deliberate instructional decisions on data (Roth McDuffie, 2001).

Some might suggest that elementary science teachers could get the same benefits in development of teaching practice from reading other's research reports. Reading others' research is beneficial, but not solely helpful at delineating practices that would work best for individual teachers. Scott and Driver (1997) found that while researchers may be able to conduct research in someone else's classroom, it is difficult to interpret the results, and make recommendations for teaching strategies because the researcher does not know the students as well as the teacher. However, by using a teacher research approach the teacher is able to decide which approaches are best for students. Other elementary teachers and elementary teacher educators have made similar improvements in their science teaching from using reflective teacher research (e.g. Akerson, Abd-El-Khalick, & Lederman, 2000; Dickinson, Burns, Hagen, & Locker, 1997). Indeed, several studies have pointed to the importance of action, or teacher research, in developing preservice teacher abilities to reflect on, and improve their own teaching, particularly in the field of science, with the support of a university researcher (Chandler, 1999; Fueyo & Neves, 1995; Scott, 1994; Stanulis & Jeffers, 1995; van Zee, 1998; Winograd & Evans, 1995). Feldman and Minstrell (2000) described a lengthy process through which one teacher developed a teacher research agenda and the ability to conduct action research to improve his teaching of science. The teacher claimed that action research became a natural part of his teaching over time, allowing him to track his effectiveness and influence on students while he is teaching.

There is evidence that elementary teachers need experience in inquiry (Kielborn & Gilmer, 1999) and in professional development for teaching science (i.e., Atwater, Gardener, & Kight, 1991). Action research promises to give teachers an authentic experience in inquiry on their own science teaching as a professional development tool. Thus, it is recommended that teachers learn to use action research as both an approach to inquiry as well as a tool for professional development in science teaching.

Methods for Preparing Elementary Teachers to Use Action Research

Our students completed an action research project as part of a Master in Teaching (MIT) program. This two-year masters degree program served preservice teachers who already held a baccalaureate degree in a field other than education and desired to become teachers. Two primary objectives of this program were: "(1) To educate teachers to become effective practitioners who…by bringing the inquiry method of a research university to bear on the entire educational process… (2) To empower teachers as reflective practitioners by helping them develop the multiple and critical decision making skills essential for today's classrooms" (University program description document). This research-based approach to developing reflective practitioners was evident in the design of the student teaching internship. Requirements of the internship included: twelve weeks in a K-8 school placement, solo teaching for at least 4 weeks; writing in a reflective journal at least once each week; completing a goals sheet at least once each week (identifying a goal for their teaching and reflecting on their success in meeting that goal); writing lesson plans for all lessons taught; developing a unit plan; completing at least four focused observations of teachers' teaching and writing a report on each observation; and completing a classroom-based action research project on their teaching.

Regarding the action research project, the preservice teachers designed their studies during the previous semester as part of a course titled "Classroom Focused Research," taught by the first author. Using two texts as a framework for study (Hubbard & Power, 1993; McNiff, Lomax, & Whitehead, 1996), the preservice teachers studied methods of designing and conducting action research, and planned original classroom-based research projects as part of this course. The action research project focused on investigating a specific teaching strategy or approach. Preservice teachers were encouraged to select a teaching strategy and content area about which they felt least secure, and in which they wanted to improve their teaching. Each preservice teacher worked with a faculty committee consisting of a chair (with expertise in the preservice teacher's selected area for research) and two additional faculty members from the Department of Teaching and Learning. The preservice teachers wrote literature reviews in their areas of study as part of a full study proposal. These proposals were submitted to the preservice teachers' chairs for feedback and reviewed three times during the semester before submitting a final version at the end of the semester. They implemented their studies the following semester during student teaching. In the month after their student teaching internship the preservice teachers analyzed their data, wrote and presented oral and written reports of their studies to their faculty committee.

Research Support and Results of Elementary Science Teachers Using Action Research as Professional Development

After preparing four groups of preservice teachers to conduct their own action research projects in their internship settings, we have experienced many of the students' frustrations and successes. Interestingly enough, the frustrations are present predominantly in the design of the study. Preservice teachers began with a negative attitude toward conducting teacher research, similar to the negative attitudes with which they often come to the science methods classroom. To be sure, there were still frustrations while in the field conducting the research, analyzing the data, and writing up the research. Most felt quite overwhelmed at the idea of conducting action research in combination with the already challenging activities of student teaching. For example,

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one student summarized her feelings of both seeing the benefit of action research and also feeling a bit anxious about it when she said,

> I know that it's beneficial because it's really going to force us to plan what we are doing. And to look at a specific area of interest to us. And to work on developing it…, but it is daunting, definitely! It's hard to know how data collection will fit in with normal teaching.

Reassuring the preservice teachers that they indeed, can do both concurrently, and that the research can support their development as a teacher, is crucial. One suggestion that has worked for us is to invite a previous student, now in the classroom, to share their research as well as experience conducting that research during their internship experiences. It is inevitable that the previous student will share that the work is difficult, but worthwhile in their professional development.

The preservice teachers generally had difficulty thinking of a researchable question, tending to have a question that is too broad, such as comparisons of several teaching strategies over a four-week period, or that was focused on something extrinsic to the development of their own teaching practice, such as playing background music while students work to see that effect. However, with support from the course instructor, and each student's individual discipline chair, feasible designs that focus on teaching strategies were completed, and the preservice teachers then implemented these in their internships.

When the preservice teachers completed writing their final reports of their action research was where the successes really shine. They were excited to share their new-found, data based knowledge. It was evident from their animated presentations that they were excited about their results, and were anxious to share their information with others. Many chose to also present their work at a University-wide Research Symposium, competing with all disciplines. In fact, in two of the last three years of the symposium, top prizes were awarded to education student projects, which was a wonderful feat given the judges are multidisciplinary and the students were competing against the hard sciences as well as social science studies. Many of the science action research projects have also been presented at national conferences (Akins & Akerson, 2000; Baker & Roth McDuffie, 2000; Bohrmann & Akerson, 2001; Burke & Akerson, 2002; Dickinson & Reinkens, 1997; Jardine and Roth McDuffie, 2001; Kelso & Akerson, 2000; Liu & Akerson, 2001; Nguyen & Roth McDuffie, 2001; Nixon & Akerson, 2002; Pringle & Dickinson, 1999; Stine & Akerson, 2001; Wright & Dickinson, 1999;) Additionally, one preservice teacher's work has been published in a peer reviewed journal (Bohrmann & Akerson, 2001), two are in press in peer reviewed journals (Akerson & Reinkens, 2001; Liu & Akerson, 2002) and another is under review (Akins & Akerson, 2001). Undergoing the extra work required to present a paper at a national level, as well as submit and publish a paper in a peer-reviewed journal speaks volumes to the value these preservice teachers placed on their work. Nonetheless, they needed support in these endeavors, and it is unlikely that any would have pursued disseminating their work to a wider audience were it not for support from a university researcher. It is also the case that these preservice teachers would be unlikely to initially engage in action research and attempt different approaches to teaching and learning were it not for being required to do so, and being supported by the university researchers. A student spoke directly to this issue when she said:

> [Another preservice teacher] and I were talking on the phone the other day, and she said "Wouldn't it be easier if we didn't have to do the research projects?" And I said, "Yeah, you know, I had thought about that too. It would have been a lot easier." And then…I realized that it pushed me out of that comfort zone, at least in [the one area I was researching]. Where if I didn't have that requirement I would not have worked at incorporating new ideas in teaching. I asked her, "Do you think you would have done what you did in [innovative teaching] if you hadn't done the research project?" And she said, "No!" So if nothing else, it pushes us out, at least in one content area, out of our comfort zone [to try something different].

One preservice teacher stated that "including action research is the difference between just working and being a professional." Another stated, "I hate to admit it, but doing the action research project forced me to test teaching methods I may not have otherwise tried. And it made me think about what I was doing."

Thus, we have found evidence that action research has helped with the professional development in science teaching of our preservice teachers. It has also given them an authentic, meaningful, contextualized inquiry experience.

Recommendations for Including Action Research in Elementary Science Teacher Development

We have had successful experiences in using action research for elementary science teacher development. The teachers with whom we have worked have received professional development opportunities as they research, in their own classrooms, how strategies for teaching science work with their students. Additionally, these teachers have experienced an authentic inquiry project. While not the same as a scientific inquiry, the process parallels what scientists do, particularly social scientists, and gives them a model of inquiry they may choose to have their students use.

From our experience in using action research to help preservice elementary science teachers both improve their teaching of science and undertake an authentic inquiry experience, we have six recommendations. These recommendations include (a) emphasize that preservice teachers focus on a meaningful, researchable question that focuses on their teaching practice, (b) encourage preservice teachers to select areas for research about which they are least familiar, (c) provide university support for the preservice teachers throughout all phases of the project, (d) focus preservice teachers on a stringent research design, (e) encourage students to realize they can conduct the research project, and (f) encourage preservice teachers to disseminate the results of their studies.

First, preservice teachers should select a research question that is meaningful to them, and that focuses on their teaching practice. If the requirement to focus on teaching practice is not there, then the preservice teachers may choose a research question that is not conducive to professional development. For instance, preservice teachers could select a project that studies the effects of natural light on student science performance. While this could, in theory, be argued to be a valuable study, it would not lend itself to professional development of science teachers. Thus, preservice teachers should focus on designing studies that focus on development of their science teaching, such as using conceptual change teaching strategies to promote student learning, or exploring interdisciplinary approaches to teaching science.

If preservice teachers could choose to study any teaching strategy or content area they wish, they would often select a literacy focus. Yet they often need the most professional development in areas they would not choose to study, such as science. It is for this reason that we recommend encouraging preservice teachers to design studies that can help them improve their teaching of subjects for which they feel the least confident. Once they implement teaching strategies, and collect and analyze data attesting to the effectiveness of the strategy, they may feel more comfortable about using it, and teaching that content area. They will, at the very least, have more experience in teaching that content area than they would if they had conducted a literacy study.

Third, university faculty should work closely with preservice teachers throughout the entire process of designing the studies, data collection and analysis, and writing. Regular feedback during each phase is essential for students new to research. Helping preservice teachers design viable, meaningful studies, as well as collect and analyze the data, is very important. As part of this process, university faculty need to encourage students to think carefully about the implications of their findings. Often students report findings and end their research report without interpreting these findings for their own practice and for others' practices. For example, in Nixon and Akerson (2002) the preservice teacher originally concluded her paper with the result that her elementary students' interpretations of their own science investigations became more superficial when constrained by various writing forms in her attempt to investigate how science can influence language arts skills. When asked to think about interpreting this result, she realized that while science and language arts can be thought of as interdisciplinary at times, there are still times where disciplinary instruction is most appropriate in each. Appropriate disciplinary instruction allows for appropriate development in each discipline, and for teachers to help students to meet each discipline's objectives. Without prompting from her university mentor, she may have missed interpreting this finding, and more generally, she may not have thought beyond the data.

Fourth, focus preservice teachers on a stringent research design. They will learn little about inquiry without a robust design, and will gain valuable insight in both inquiry and educational research with a good design (Lederman & Niess, 1997). Again, preservice elementary teachers have had little, if any, experience in conducting inquiries, thus they will require support. Preservice teachers should conduct a fairly thorough literature review while designing their studies and prior to data collection. Through this process they: gain an appreciation for "what is educational research" from reading others' work (clarifying the difference between systematic research and simply reflecting on practice); clarify their own research questions/problems; and certainly learn what we already know/have established in the field. While most of our work has been with preservice teachers, one inservice teacher who took a "Teacher as Researcher" methods course stated, "Just reading about all the research related to my study helps me see how my teaching might change." Thus, even the act of reading related research can help teachers see a need and process for change. In our program, the review of literature took place in the research course semester, and required preservice teachers to review at least five outside empirical research sources as backgrounds for their own study. As their work progressed, even through data collection and analysis, most preservice teachers continued to read related research, and modify their literature review. Thus, they spend almost an entire school year reviewing related research, and their final literature reviews are much longer than the original five required.

As part of a stringent research design, preservice teachers should develop carefully a plan for data collection and analysis. This plan may include a timeline for these activities. Even if the students deviate from this plan during the study, having a structure in place helps them to stay focused on their research when the demands of teaching might pull them away. This plan will help them see the nature of scientific inquiry—a plan for investigation that can deviate as the investigation is conducted.

Fifth, preservice teachers need encouragement that they can actually conduct a meaningful inquiry on their science teaching. Again, they are generally quite intimidated about the project especially in the early stages of the design of the study, but continue to need encouragement throughout the study. Beyond the course the preservice teachers take to design their studies, we advocate monthly seminars at which they bring questions, data, problems, or other matters for discussion. These monthly seminars have been approximately one and a half hours in length. The focus is on the preservice teachers' inquiries. The format is informal, allowing the preservice teachers to raise questions regarding data collection, analysis, and interpretation, and to receive feedback from both their peers and a university researcher. Additionally, the preservice teachers should be encouraged to maintain contact with their university chairs during the entire implementation of their plans.

Finally, we recommend encouraging preservice teachers to disseminate the results of their research. When the preservice teachers recognize that their research can reach a wider audience, they are more determined to design a more stringent plan and more thoroughly examine implications of their findings. They realize that the results of their research can not only benefit them and their own teaching, but also other teachers and teacher educators. This makes the action research a valuable addition to their development as elementary science teachers. It gives them the knowledge that their work is important, and given the fact that other teachers and teacher educators will read their work, could boost their confidence in teaching science.

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PRESERVICE SECONDARY SCIENCE TEACHER APPRENTICESHIP EXPERIENCE WITH SCIENTISTS

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Theoretical Framework

According to the *National Science Education Standards* (National Research Council, 1996), Standard A states that science students must have the abilities and understandings necessary to do scientific inquiry. The standards explicitly state that small groups of students should hypothesize from prior experiences, construct explanations, evaluate explanations, design investigations, conduct experiments, gather data, analyze data, conduct peer reviews, communicate arguments, and reflect on the inquiry process.

Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) describe inquiry in detail stating that students who participate in authentic scientific investigations have a reasonably accurate picture of inquiry in real science. The *Benchmarks* state kindergarten students should be involved in exploring phenomena. With advancement to the higher grades, students should be involved in hypothesizing, investigating, data collecting, data manipulating and presenting. The *Benchmarks* ambitiously affirm that the students should be involved in at least one major investigation, where the student frames the question, designs the approach, estimates the time and cost, calibrates the instruments, conducts trial runs, writes the report and responds to criticism. If the student participates in "progressively approximate good science, the picture they come away with will likely be reasonably accurate"(AAAS, 1993).

At the state level, states have incorporated inquiry into their teacher preparation standards. For example, Tennessee Teacher Licensure Standards state that the preservice teacher must have the knowledge and skills to accomplish the following: "demonstrate processes of science such as posing questions, observing, investigating phenomena, interpreting findings, communicating results and making judgments based on evidence and design" and "conduct inquiry-based, open-ended investigations" (p. 8-1, State of Tennessee State Board of Education, 1997). Additionally, as of September 1, 2001, Tennessee licensure guidelines dictate that all preservice science teachers will engage in an open-ended inquiry of long-term duration within their major. (p. 8-7, State of Tennessee State Board of Education, 1997).

At the national level, the National Science Teachers Association, NSTA, in association with the National Council for Accreditation of Teacher Education, NCATE, require the following standards for pre-service science teacher preparation:

- *1.1.1.C* Conducts limited but original research in science, demonstrating the ability to design and conduct open-ended investigations and report results in the context of one or more science disciplines (p. 2)
- *3.1.1.A* Plans and implements data-based activities requiring students to reflect upon their findings, make inferences, and link new ideas to preexisting knowledge (p.13)
- *3.1.1.B* Plans and implements activities with different structures for inquiry including inductive (exploratory), correlational and deductive (experimental) studies (p.13)

- *3.1.1.C* Uses questions to encourage inquiry and probe for divergent student responses, encouraging student questions and responding with questions when appropriate (p. 13) (NSTA/NCATE,1998).

Additionally, two National Science Education Teaching Standards address inquiry explicitly. Standard D states that teachers should "structure the time available so that students are able to engage in extended investigations and create a setting for student work that is flexible and supportive of science inquiry;" while, Standard E states that teachers should "model and emphasize the skills, attitudes, and values of scientific inquiry" (National Research Council, 2001).

In order for science teachers to facilitate student inquiry efforts, teachers must be able to perform investigative experiments utilizing appropriate sample size, controls, duplicates, data collection and scientific writing. To equip teachers with such an experience, teacher preparation programs are implementing various strategies for obtaining inquiry methodologies. An entire strand, Strand 4 Teacher Education, is devoted to science teacher preparation reform from the National Association for Research in Science Teaching (NARST) presentations (NARST, 2001). The strand presentation, conducted March 2001 in St. Louis, included various session titles with the following key words: inquiry-based science, authentic science, teacher preparation reform, and constructivist science. These key concepts, as defined by researchers in the field of science education, explicitly address the implementation of an authentic inquiry classroom environment required by the National Science Education Standard A. Some titles from the NARST Strand 4 presentations are:

- Teachers Learning About Nature of Science in *Authentic Science Contexts: Models of Inquiry* and Reflection (p. 53)
- Teachers' Beliefs About, Perceived Implementation of, and Demonstrated Classroom Use of *Science Reform Principles* (p. 44)
- Arizona Collaborative for Excellence in the Preparation of Teachers: The *Reform of the Professional Preparation of Science Teachers* (p. 83)
- Improving the *Connection* Between Pre-Service and In-Service Teacher Education (p. 67)
- *Inquiry in Scientific Communities* and Teachers' Perspectives on that Inquiry (p. 93)
- Narrowing the Theory-Practice Gap: First Year Science Teachers Emerging From a *Constructivist Science Education Program* (p. 67)
- Learning to *Do Research*: Struggles to Develop Causal Questions (p. 40)
- *Understanding and Teaching Scientific Inquiry*: An Evaluation Study of a Statewide Professional Development Program (p. 40)
- *Bridging Classroom Inquiry and Preservice Preparation*: Using Multiple Representations to Teach Mathematics and Science (p. 40)
- The *Use of Open Inquiry Projects in Science Methods Courses*: Implications for Subsequent Classroom Practice (p. 40)
- Toward *Inquiry-Centered Science Teaching and Learning*: Classroom Research Into an Elementary Science Methods Course (p. 75) (NARST, 2001).

The previous titles are based on educational reform of science teacher preparation; the researchers presented the reform method implemented at their particular university or institution. Some research is the implemented idea only; while, some research includes statistical data on the effectiveness of a particular methodological approach. The science teacher preparation methods varied from implementations in the methods courses, to the science courses, to the K-12 schools. The goal of the varied reform implementations is to provide preservice teachers the skills and experiences to effectively utilize a constructivist inquiry–based approach in a K-12 setting.

The Science for All Americans (1990) text, coinciding with the Project 2061 Benchmarks, explicitly defines the scientific world view, scientific methods of inquiry and the nature of the scientific enterprise. The authors state that

> scientists share certain basic beliefs and attitudes about what they do and how they view their work. These have to do with the nature of the world and what can be learned about it . . . Scientific inquiry is not easily described apart from the context of particular investigations. There is simply no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge…Although features are especially characteristic of the work of professional scientists, everyone can exercise them in thinking scientifically about many matters of interest in everyday life. (p. 2 & 4)

Since tacit knowledge of the scientific discipline is inherent in the context of that particular space and time, science teacher preparation institutions can utilize the science research facilities at their particular institution to introduce preservice teachers to the realm of the scientific enterprise and environment. This particular approach is used at a large southern Research I institution in the Spring of 2000. The goal of the apprenticeship opportunity is to teach preservice teachers about true authentic science by pairing them individually with a "real" scientist doing "real" science. Therefore, the preservice science teacher's research experience is grounded in the field; the preservice teachers do scientific research at the bench alongside the elbows of a "real" scientist. By using the apprenticeship model, science teacher educators provide a "real" science laboratory experience, where the knowledge is transferred from the expert scientist to the novice preservice.

Apprenticeship Models

Schwartz, Lederman, & Crawford (2000) conducted and analyzed an apprenticeship model at a mid-sized Western university. Their study measured Nature of Science (NOS) beliefs –not inquiry abilities–by analyzing interviews, reflective journals, data journals, participant observations and pre- and post-questionnaires. The overall finding of their study "suggested [that] the perspective held by the intern is perhaps the most critical factor in determining the learning outcomes in regard to NOS." The participants needed a philosophical perspective combining NOS and inquiry; the researches believed that "doing science is insufficient for one to adequately understand the NOS." This particular model was utilized at a different college site with slight variations in the research experience; however, the results depicted the same NOS conceptions (Westerlund, Schwartz, Lederman, & Koke, 2001). As stated earlier, these particular studies were not measuring inquiry capabilities; however, they were examples of apprenticeship models incorporating an authentic science experience into their teacher preparation programs.

A northeast land-grant institution and the National Radio Astronomy Observatory at Green Bank, West Virginia were the sites for another apprenticeship model experience (Pyle, Obenauf, Heatherly, DiBiase, Hemler, Govett, Evans, Gansneder, 1997). This model placed preservice and inservice teachers in a one to two-week summer research experience at the astronomy laboratory in Green Bank. Teachers conducted inquiry experiments with available science mentors and observatory equipment. From a generalized research problem, the teachers formulated research questions, collected and analyzed data and finally presented such data to the group. After the apprenticeship experience at the institute, the teachers planned, developed, implemented and evaluated a student-centered inquiry-orientated scientific investigation for their school. To reinforce the apprentice research inquiry experience, teacher educators utilized inquiry methods in their method's courses. Lastly, to increase the research transference into the classroom, all attempts were used to place the preservice science teacher with a mentoring teacher who was a previous Green Bank institute attendee.

Hemler (1997) researched the Green Bank program by examining the effectiveness of the preservice apprenticeship component at the astronomy laboratory. From her classroom observations, Hemler (1997) cited "five projects of the seven implemented by participants [as] successful research experiences for students." Hemler's study contended that the astronomy laboratory apprenticeship remains a "viable constructivist model for exposing preservice teachers to science research and transferring that experience to the classroom."

The program Science For Early Adolescence Teachers (Science FEAT) utilized the apprenticeship model for practicing middle school science teachers in North Florida and South Georgia (Spiegel, Collins, & Gilmer, 1995). As reported, these particular middle school science teachers had never "engaged in the practice of science nor fully understood what scientists do." Their apprenticeship involved 15 research facilities and provided 25 research opportunities, supporting a possible 81 placements. The FEAT science teachers "spent 75-100 hours during five weeks engaged in some aspect of research at a level beyond that of a technician. Also, each group produced a publishable quality abstract and presented a poster of their research." In regards to the poster quality, one participating scientist responded that he "could have taken any of those posters to a regional American Chemical Society meeting."

University of Tennessee Apprenticeship Model

This research study addresses the apprenticeship science course offered at the University of Tennessee. This science course was designed to meet the state mandated licensure component that all preservice science teachers conduct or be involved with a long-term scientific investigation within their major. The course was first offered in the Spring of 2000 in response to preservice teachers' scheduling conflicts. Some science preservice teachers were unable to sign up for the Fall 1999 graduate science course "Learning and Teaching Science – Just Do It" (Melear, Goodlaxson, Warne, & Hickok, 2000).

In order to meet Tennessee licensure guidelines, the course requirements included nine weekly hours with the scientist, six seminar meetings with the science educator, and one final research symposium. Three graduate science credit hours were awarded for the completion of these requirements. The preservice teachers scheduled nine or more hours in the scientist's laboratory to work on a particular aspect of research. All seven preservice teachers gathered for a round-table discussion to reveal their research progress to the science educator, who volunteered her time, support, and guidance. A final symposium was held at the end of the year upon which preservice teachers presented their research results to all of the participating scientists and preservice teachers. The preservice teachers logged raw data, transformed data, and explained results in their scientific logbooks. Additionally, the preservice teachers reflected on the apprenticeship experience by writing in a personal journal the details of their frustrations, elations, set-backs and accomplishments. The preservice teachers submitted a final summary paper of their reflective journal.

Apprenticeship Model Theory

The apprenticeship novice/expert model was grounded within current science education research. Duit and Treagust (1998) stated "in the apprenticeship model, [that] the novice learner gets to be an expert through the mechanism of acculturation into the world of the expert." When the novice preservice teacher entered the scientific laboratory of the expert scientist, the research experience was authenticated in a manner that educational methods or traditional science courses cannot replicate. The term *authentic*, as defined by Roth (1995), was "the activity in which [the] learner engages has a large degree of resemblance with the activity in which core members of the community actually engage." The apprenticeship model included the theories of social constructivism (Vygotsky, 1978) along with situated and distributed learning (Roth, 1995). The novice tacitly acquired methodological and procedural knowledge from the interpersonal or social interaction with the scientist. The novice then intrapersonalized, or individualized, this information.

Methods

Three primary researchers triangulated the interview transcript, laboratory journal, and reflective summary data to examine the apprenticeship program participants' experience. During the apprenticeship, the preservice teachers wrote in a bound laboratory notebook and personal reflective journal. At the end of the laboratory study, the student/novice wrote a short paper about their experience. Approximately one year after the apprenticeship experience, the researchers performed a short interview of the participants. The transcribed interview data was the participant's disclosure of their "real experience" of the science laboratory apprenticeship. The purpose of this study is to determine if there was transference of the apprenticeship experience into the classroom setting during the internship year.

Research Questions

The central question of this study is:

What is the value of a novice/expert apprenticeship between a scientist and preservice teacher at the University of Tennessee?

The primary and secondary interview questions are:

Describe the experience.

How involved were you in the design of the study?

Design an experiment.

What does a scientist do?

How did the course prepare you for teaching?

How could you use this experience in the classroom?

Participants

Three of the seven pre-service science teachers involved in the apprenticeship program participated in this study. At the time of the interview in Spring 2000, all three were completing course requirement for teacher certification. Two of the three participants had conferred biology degrees, while one had a biology minor. All three female participants were teaching two science courses at a local high school in order to complete certification requirements to obtain biology certification at the secondary level. The three novice teachers, their corresponding expert scientists, and their research topics are listed in Table 1.

Please insert table here.

Table 1

Three Novice/Expert Participants and Research Topics

Preservice teacher[a]	Scientist[b]	Research topic
Lynne	Dr. M Dr. C	Effects of shade treatment on rhizome growth of Helianthus eggertii (Asteraceae)
Michelle	Dr. S	Distance test for catilipsis of Agelenopsis aperta
Val	Dr. G	Echolocation call of the Mexican free tailed bat (Tadarida brasiliensis) at high altitudes

Note. Pseudonyms are used for actual names of the [a]preservice teachers and [b]scientists.

Data Analysis

The three researchers compiled the participant's summary paper, laboratory journal, and interview transcript as a detailed portfolio of their experience. The first two principal researchers then coded and analyzed the portfolios for themes. To reduce investigator bias, the two researchers coded and analyzed each portfolio individually before collaborating to reach a consensus on common emergent themes. The common themes that emerged from the three different experiences are presented in this study. This study is specifically based upon these three participants and their experiences at the University of Tennessee; no attempts are made to generalize the findings beyond these participants.

Results

Lynne

Lynne graduated from a small religious college before arriving at the University of Tennessee. During Lynne's apprenticeship, she worked with Dr. M and Dr. C from the Botany department. Lynne arrived at the laboratory after the experiment began and spent her laboratory time doing measurements of rhizomes. From Lynne's interview transcript and journal entries, four themes emerged. The four themes included: data collecting attitude, vocabulary restrictions, project ownership, and experimental understanding.

The first theme was Lynne's dislike or disdain for the collection of data, which involved measuring the length, number, biomass and root tips of plant rhizomes. Lynne performed the data collection for approximately seven hours a week. Lynne described this collection task as "monotonous, boring and very, very old." Negative tones, expressions, and feelings about the data collection pervaded the interview from Lynne's statements such as, "my job was to count," "I got stuck in the collecting of data," "I was doing the same thing the whole semester, "and "I was just the data collector." Lynne stated that she does "the same thing so it didn't make [her] like it a whole lot." Additionally, her comments in her journal expressed her exasperation on the seemingly infinitesimal amount of data to collect from statements such as "there are tons of roots still left to measure," "[excavating roots from boxes] takes a long time" and "I worked the whole time and did not finish one box." Overall, from her collection experience and from watching the experiences of others in the lab, Lynne felt scientists basically "came in everyday and did your experiment; worked on it all day long; went home and came back and tried something different."

The second emerging theme was that the scientists use technical oral and written vocabulary foreign to Lynne. During the weekly meetings of the laboratory scientists, the scientists discussed their research. Lynne stated that she "wasn't familiar with the terms and vocabulary they were using and the ideas and theories that they were working with because [she] hadn't been exposed to any of that." Lynne repeatedly stated that the papers and discussions "were way over [her] head." When reading scientific papers, she would "read a paragraph or a sentence, and would…have no clue what [the] sentence just said." The scientists did however "try to break it down on [her] level and explain [the papers]." However, during seminar meetings, Lynne felt that she "had no clue … [she] felt out of place." The lack of a common discourse between Lynne and the scientific cohort possibly caused isolation, thereby undermining Lynne's confidence.

The third theme was an additional lack of understanding from the fact that Lynne's experiment was "already set up and planned." When Lynne arrived at the lab, Dr. C gave her "a basic understanding of the experiment and how it [was] set up." Therefore, Lynne felt "basically the project that [she] was working on … was [Dr. C's] project." Due to the omission of Lynne devising the research question and lack of involvement with the experimental design, Lynne acquired very little ownership of the rhizome research.

The last theme emerging from Lynne's data was the lack of understanding in designing an experiment. Although, Lynn stated that she had "a better understanding of how to help people set up and come up with an idea that they want to [do a] project on," her explicit explanations of how to perform this goal lacked canonical scientific knowledge and protocol. When asked to design an experiment determining how much water a plant would need to survive, Lynne displayed a lack, or limited, understanding of sample size, data collection, and dependent variables. Lynne "said six, [but] I am not sure" for the sample size, and then proceeded to explain "[how] ever many variables you want, that is how many plants you need." The following excerpt of Lynne's response to a hypothetical experiment supported the previous claim of her lack in experimental knowledge after the apprenticeship:

> I think you record every time you water the [plants]. You could take measurements every week, every other week of the plant. You

> could … hum, write down the color of the leaves, if is dying, if it is falling over, if it is wilting. Hum, just those kinds of measurements to see if it is surviving or … take your results, the [plants] that survived and the [plants] that didn't or the [plants] that some might have been watered too much and also died and find the [plants] that seem to do the best and say that based on my experiment, these plants, this amount of watering, ever so often, was good amount for this particular plant to survive and this much was too much and this much was too little and somewhere between, lie whatever you have between.

From the previous statement, Lynne demonstrated zero understanding or need for quantitative, numerical data, even though her actual experience was exactly that. Her entire semester experience (12 x 7 hrs = 84 hrs) was spent measuring rhizome roots. Most of her data explanation of her hypothetical experiment was qualitative and observational, not quantitative.

Michelle

Michelle's degree included a Biology minor. During Michelle's apprenticeship, she worked with Dr. S, a professor in the Ecology and Evolutionary Biology department. Dr. S has done extensive research on arachnids and had already chosen an experiment for Michelle's apprenticeship. Michelle conducted experiments on the distance for catilipses (cationic state) for funnel web spiders. Michelle used three different apparati to test the distance at which the male could release a pheromone that would knock out the female so he could safely mate with her. Data analysis of Michelle's experience showed four emerging themes. The four themes included: lab environment, project ownership, classroom confidence, and experiential value.

Michelle spoke positively about the lab environment in which she completed her apprenticeship. She expressed comfort in the lab in that Dr. S was "very receptive to what [she] had to say" about the experiments. Michelle didn't have the same background as some of the other people working in the lab, but she stated that Dr. S "didn't treat [her] any different than any of the other people coming and doing research in her lab." Michelle "felt like [she] knew what was expected of [her] and what [they] were doing and why [they] were doing it," and from that understanding, Michelle exhibited a sense of ownership of the project. When discussing the research, Michelle often used the pronoun *we*, referring to herself and Dr. S, as from the following statements of "we were testing" and "we would design." Overall, Michelle "felt like [she] was really part of something."

The third theme was an increase in confidence in the secondary science classroom. Michelle felt this apprenticeship "gave [her] more confidence" as she began her internship in the classroom. "It got [her] ready to be in the classroom". The apprenticeship "helped [her] feel like [she] was a little bit more prepared in helping [her] students going into the lab". She felt more confident explaining experiments to the students and "qualified to talk about science because [she] didn't just read it out of a book."

To Michelle, scientific experience was invaluable in the classroom. "If you can relate [science] to [the students] or give an example in your life, they tend to listen more." During Michelle's internship experience, she found that "unless you have some good experience to relate to [the students], they don't care." Michelle felt prepared for the classroom by seeing the "other things in [Dr. S's] lab and [seeing] the stuff that was going on, and [to be] around the [lab] setting." Michelle felt "this experience will be helpful to [her] in the classroom because [she is] better prepared to guide students in asking their own questions." She felt if she could "help [her] students learn to ask questions about things they are interested in, then [she had] accomplished something." "By asking questions and discovering what one wants to know, they have begun a scientific investigation."

The final theme was that Michelle thought this was a valuable experience. She "gained a better appreciation of performing a scientific investigation. … and it taught [her] about more than doing a literature search and compiling data." She "learned how to write up a protocol and … scientific paper." She found it very helpful to write her own scientific paper about her study. Even though she didn't believe "the inquiry design for most high school classes would work," she did believe that this apprenticeship was "a very valuable learning experience."

Val

Val had a degree in Biology and had worked at a scientific laboratory before deciding to become a science teacher. During Val's apprenticeship, she worked with Dr. G from the Evolutionary biology department. She worked independently alongside biology graduate students analyzing prerecorded audiotapes of bat echolocations. Triangulation of the data sources revealed four emergent themes: attitudinal change, authentic experience, project ownership, and technique transference.

The first them of attitudinal change began as "[Val] first heard about it [in that she] was very irate," and she "was not so thrilled about having to participate." The apprenticeship started "out [as] a very negative experience for [her]. [She] thought, you know, this is ridiculous." The initial resentment was due, in part, to economic factors, because Val had to terminate her employment in order to fulfill the research requirement. However, as Val became increasingly involved with the project, she "got into it and … loved it." She viewed her work as personally relevant and "would go over to the [bat] lab … even when [she] wasn't supposed to; [she spent] extra time…in the evenings and stuff." As her attitude increased positively of the apprenticeship, so did her attitude of bats. After research bats, she referred to them as "cute little bats," and actually became a "bat buff." At the time of the interview, a year after the apprenticeship, Val still remembered the lab experience fondly. She still thought "wow, being in a lab, I just love the lab environment," and "when I was over in the lab, I felt so at home. I loved finding out new things. I loved presenting findings and talking about what I found."

The second theme of the apprenticeship experience was identified as authentic scientific practice. She had been "exposed to the reality of 'doing' science." She stated that she had never done a laboratory experiment in which the outcome was not already known. Some components of her authentic scientific practice included making procedural adjustments ("tinkering"), conferring or consulting with experts, and sharing/defending findings within the community of scientists. Val's tinkering consisted of "figuring out … what would be the best way to list data, so that [she] can keep track of what's going on." From her tinkering, she also found "that it would be more efficient to [download] sounds to the program Bat Calls, then go back and analyze them." Val then discovered "it would be more efficient to save several calls/file."

The third theme of project ownership was apparent during the laboratory training and data presentation. Although Val was not involved in the initial formulation of the research question, she clearly had a vested interest or ownership in the inquiry analysis and outcome. Through her involvement from beginning to the end of the project, she felt that "when you have that finished product…it gives you a tremendous ego boost…[that] you have accomplished something." Dr. G oriented Val to the laboratory by training her to use specific laboratory bat-call analysis tools. Val examined copies of Dr. G's work and viewed a PBS broadcasted videotape of the bat project. Val stated that Dr. G "was always available for assistance"; he "was really helpful to [her] in the analysis part and in getting [her] going." Val felt during the final analysis, "[they] worked the closest" because Dr. G assisted her in summarizing her findings before the symposium presentation. Val "loved [presenting]; she "got so excited" that she "did not want a time constraint." The presentation experience appeared to be the highlight of the apprenticeship for Val. In addition, Dr. G conferred with Val that "if this gets published, [your] name will be on it." The possibility of "getting published [and] having your name out there [was] an ego boost" to Val.

Val expressed the final theme of technique transference by discussing her inability to incorporate the process of authentic scientific inquiry into her teaching practices. During the internship, Val believed that her enthusiasm and increased appreciation for science and bats would "rub off" on her students. However, what she discovered was that "in the classroom, things are very different. It's not that [she] wouldn't want to, it's just that it is very difficult to take students and get them involved in long-term research projects." Val believed "it's very difficult [and] I can, of course, do the cookbook labs…[there isn't] a time where I could get them involved in any long-term project." Most shocking was that Val believed that she "couldn't do research in public schools [or specifically] do research with [a] 10th grade class. It's just not done, as far as scientific research." Val viewed teaching science and doing scientific research as mutually exclusive at the secondary level. Val stated that one "can do qualitative research…for education, but … it's just not there to do actual research, laboratory research." Val attributed this lack of transferability to end-of-course competency exams, which required certain amounts of content coverage. Val stated "the time is not there," as there are "certain things [one] has to teach" Secondly, she refered to lack of student interest. Val "felt [the students] find the answer, and they were happy with that one answer and they didn't want to move on."

Discussion

From the apprenticeship experience, all three preservice teachers, the novices, learned a scientific skill from their mentoring scientists, the experts. During the semester, the three participants worked alongside a scientist in a university laboratory, as they learned various procedures modeled by the scientists while situated in the context of the ongoing experiment. No single participant learned a scientific skill from reading a procedural manual only. Each preservice teacher actively observed and participated in learning the scientific procedures by close proximity with the mentoring scientist. Specifically, Lynne demonstrated appropriate protocol for laboratory procedures in rhizome measurement, Val for bat call interpretations and Michelle for pheromone distancing in spider mating. From these various apprenticeship experiences, the researchers assumed that content, procedural, and tacit knowledge are distributed to the preservice teachers.

A discrepancy appeared in how the preservice teachers viewed the data collection phase of the experimental. The overall experimental process should have involved devising a question, designing an experiment, collecting data, and interpreting the results, and these experimental steps should not necessarily be linear as written. These teachers entered the apprenticeship experience at various intervals of this process. Lynne expressed repeatedly her dislike for data collection; she was "bored" and saw the data collection as "tedious and monotonous." However, Michelle did not view the data collection negatively. Even though Michelle stated that data collection was "repetitive," she took a positive stance and tried to learn something new from the experience every day. Also, Michelle utilized this time as an attempt to overcome her slight case of arachnophobia. Val did not personally collect the bat call data; however, she expressed a "love" of listening to and coding the various calls. Val even spent additional hours in the lab to listen to the bat call recordings.

To explain this discrepant attitude in data collection, the researchers surmised that the key element was the involvement of the preservice teacher in the overall experimental process. Once Michelle was shown research articles and spider-mating laboratory set-up procedures, she worked in designing the next experiment. Michelle collaborated with her mentoring scientist, and after viewing the data, she and the professor decided collectively what the next experimental design should be. Michelle was involved in most facets of experimental research – reading literature, collecting data, modifying experiments, analyzing modification, evaluating data, collaborating with colleagues, and writing research. Val was involved in the bat research in the same manner – interpreting calls, writing research, critiquing definitions, and collaborating with scientists. Valued above all, Val was offered a stipend to continue the research over the summer; her name was to appear on future related published materials. In her view, Lynne did not experience many of the research elements; she saw herself as "just the data collector." Lynne's experiment was already designed upon her arrival into the laboratory. She also had limited experience in evaluating the data and writing results.

Therefore, the proposed link to an improved apprenticeship attitude was to increase involvement in the overall experiential process. This involvement related directly to feelings of ownership of the learning. The two participants having a vested interest in the overall scientific process had an increased positive experience than the one who did not. The increased involvement coincided with the increased overall ownership.

An area of concern among the researchers occurred with one of the overall goals of the apprenticeship experience–the transference of the short-term laboratory experience to the science classroom setting by the use of inquiry investigations. When asked directly how the apprenticeship experience had affected their current teaching practice, the participants stated many reasons why they felt they could not implement that type of classroom methodology. Arguments such as time limitation, content coverage, and end-of-course tests prohibited their use of long-term or short-term investigative approaches.

Specifically, Val was concerned with lack of student interest in anything longer than a one class period experiment; she stated the experiments would not keep student interest. Val also stated that scientific research could not be done in a 10th grade science class; the research environment and science classroom are just "two different worlds." Michelle was more optimistic about using her research experience in the classroom, as she wanted to relate the content to the students by discussing how she had "done science." Michelle saw value in taking a question through to a final research paper. However, Michelle struggled with experimental implementation in the classroom. Michelle wanted to do other things than those listed in the textbooks, but she didn't know how. Michelle wanted references that would give her additional resources in how to implement research methodology into the classroom. Lynne displayed a lack of experimental design and understanding, and without this comfort, she did not implement long-term investigative experiments.

Future Implications

Implications for future studies could involve following the participants during their first years in teaching to determine if they use or if their attitude changes toward their ability to do inquiry. Modifications in the scientific apprenticeship, such as training mentoring scientists and extending the allotted research semester, could be implemented and measured. Extending the research experience to two or more semesters could allow more time for the preservice teacher/novice to become acclimated within the laboratory culture. This extended time could also alleviate the difficulty of completing an entire research problem from beginning question to ending results during one semester. By training all mentoring scientists to include certain inquiry research attributes, the preservice teachers would have an increased comparable research experience. Comparison of the apprenticeship program to the other inquiry teacher preparation courses could be evaluated from the teacher's chosen methodologies for instruction in their secondary classroom. In conclusion, in order for preservice teachers to comply with the inquiry research state and national standards, teacher preparation institutions must consider more avenues in giving teachers opportunities to perform some kind of authentic research experience. The best approach in offering this experience remains under debate.

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LESSON LEARNED, FIVE YEARS OF SCIENCE AT INTASC

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What is INTASC

In Fall, 1996, INTASC (Interstate New Teacher Assessment and Support Consortium) initiated a project to develop standards for beginning science teachers and a performance-based assessment including a scoring system aligned with these standards. This project was completed in Fall, 2001. In this presentation, after a brief overview of INTASC, I highlight three activities of the INTASC Science Project describing the activity, issues and lessons learned. The activities are the development of standards, the development and implementation of a portfolio handbook for assessment, and the development and implementation of a scoring system and the training of scorers for evaluation. The presentation concludes with a review of the relationships between standards, assessment and evaluation, some overall lessons learned and some speculations about the future. This presentation acknowledges and honors more than 200 science teachers, science teacher educators and others who have worked on this project.

INTASC evolved from the California-Connecticut Consortium, which was formed in the late 1980's, as the National Board for Professional Teaching Standards (NBPTS) [NBPTS, 1989]. NBPTS was setting high standards for experienced teachers with rigorous and realistic modes of teacher assessment and the Teacher Assessment Project at Stanford (Collins, 1991) was conducting research on alternative modes of teacher assessment. INTACS is intentionally aligned with NBPTS and more recently AACTE and NCATE.

INTASC, a unit within the Council of Chief State School Officers (CCSSO) is a coalition of over 30 states whose representatives join together to consider issues in initial teacher preparation and licensure. According to their website

> INTASC's work is guided by one basic premise: An effective teacher must be able to integrate content knowledge with pedagogical understanding to assure that *all* students learn and perform at high levels. Its mission is to promote standards-based reform through the development of model standards and assessments for beginning teachers. To carry out this mission, INTASC provides a vehicle for states to work jointly on formulating model policies to reform teacher preparation and licensing, and provides a mechanism for states to collaborate on developmental projects such as crafting new instruments to assess the classroom performance of a teacher. INTASC also sponsors a series of seminars annually, bringing together state education agencies, institutions of higher education, researchers, and professional associations committed to the principles of teaching and assessment endorsed by the consortium. These seminars present the cutting edge work being carried out on these issues and provide an opportunity for formal and informal networking among the participants (www.ccsso.org/intasc.html).

As an observer and sometime participant of INTASC, it appears that INTASC has assumed the difficult position of both being responsive to and anticipating the concerns of the member state agencies.

States pay a membership fee that entitles them to participate in discussions, set research and development agendas and have access to the products that flow from the research and development. States who wish to participate in a particular INTASC Project, such as the Science Project, pay an additional fee. This fee allows them to appoint persons to work on the project and requires them to provide test sites for the project's work. Tension in INTASC, calling for both assessment and support, is inherent. Being a member of INTASC brings to the forefront another issue - the value of learning from the experiences and using the products of other states while remaining responsive to the character, needs and wishes of one's home state.

Standards

In 1992, INTASC published the Model Standards for Beginning Teacher Licensing and Development: A Resource for State Dialogue (INTASC, 1992). Intentionally designed to align with the five dimensions of the NBPTS, the ten INTASC Core Principles - taken as a set - describe values held by the education community values. Each principle, captured in a single sentence, is expanded to include knowledge, skills and dispositions. Shortly after the Core Principles were released, work began on a staged-in series of standards documents, which interpret and apply the Core Principles to areas of typical teacher licensure such as mathematics, science and elementary teachers. Because the states who chose to participate in the Science Project almost uniformly sent persons who had worked on state science standards for students and because INTASC appointed persons who had worked either on the Benchmarks (AAAS, 1993) or on the National Science Education Standards (NSES) [NRC, 1995], worked progressed with relative speed. The committee agreed that there was no reason to "start over" and that it was essential that the INTASC Science Principles complement existing standards documents (See Appendix A). This decision revealed a tension between a reliance on and continuity with the larger reform movement and maintaining an INTASC identity. In developing the standards, one important activity was a task that matched the Core Principles, Benchmarks, and NSES. Not surprisingly, the most difficult task was around Core Principle I that focuses on knowledge of science content. Science content is defined as in the NSES, to include all aspects of science that students are to learn. The science content is organized into three areas labeled ideas, inquiry and applications.

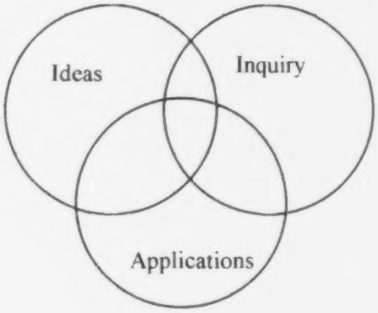

Figure 1. Three categories of science content used by INTASC Science.

Like other standards documents, the INTASC Science Standards are illustrated with sidebar examples and vignettes. Sidebar notes also illustrate interrelationships among the ten standards. Within two years, a draft of the INTASC science standards was ready for internal review and a year later a public review began.

There are five issues worth noting about the Science Standards. The first is the role of technology in science teaching. This role is neither clear nor sufficiently explicated. In science teaching, technology may refer to technology as engineering -- the solving of human problems using science -- or to instructional technology -- the use of technological tools to support teaching and learning. Technology in science teaching, in both meanings of the terms, is increasing.

The second issue is about Principle 8, which addresses a teacher's decisions about curriculum and instruction. The INTASC Core Principles and the Science Standards focus on aligning instruction with well-established local, state and national curriculum models. There is not sufficient emphasis on criteria for designing and implementing plans that support this alignment.

The third issue is a political issue. Since the INTASC Science Standards were developed, some individuals and organizations have argued that the definition of science content contained in the national documents, and consequently in INTASC Science, is too broad. They prefer that science curriculum and instruction be reduced to only teaching science ideas. The science standards committee rejects this view of science.

The fourth issue is around the need for videos that display standards- based science teaching. The science standards committee, while pleased with the vignettes, recognizes that they remain pale representations of the complexity of quality standards-based science instruction.

The final issue is that the Science Standards describe quality science teaching. The distinction between novice and experienced teachers lies in the rubric of the evaluation procedure.

I believe there are three lessons to be learned from the work in Science Standards for INTASC. The first is that, while standards are difficult to develop, they are easier to develop than to implement and evaluate. Second is that Standards are subject to political whim and that, as a nation, we in the United States seem incapable of agreeing on what knowledge is of most worth. Third, the need for individuals, states and organizations to claim ownership of and recognition for standards prevents a cohesive vision of reform.

Assessment

INTASC also proposed that four different modes of assessment should be required for beginning teacher to demonstrate competence aligned with the Core Principles. These four modes of assessment are a test of basic knowledge and skills in mathematics and language use, a test of subject matter knowledge, a test of teacher knowledge, and a performance assessment in the form of a portfolio to be completed after some teaching experience but before tenure.

Because the INTASC-member states wanted as much uniformity as possible among the portfolio directions for different teacher license categories, the INTASC Science Project began by reviewing the Portfolio Development Handbooks being developed by the INTASC Mathematics and English Language Arts Committees. We also examined portfolio development work of the NBPTS and the Teacher Assessment Project. The portfolio is organized around three entries. The first is Setting the Stage. This Entry has two parts. In the first the teachers are given he opportunity to describe their teaching situation. In the second, they describe how the instruction that will be the focus of the second Entry is aligned with overall goals for science teaching. The second entry, Instructional Design and Implementation, is the heart of the portfolio. It includes three entries. The first provides teachers an opportunity to describe and reflect on ten hours of science instruction. The second entry is organized around two lessons, one of which focuses on understanding science and on discourse, and the other on scientific inquiry. The teachers are required to submit twenty minutes of video on each of these lessons as well as reflect on what occurred. The final part of this entry is on student work. Teachers include all the work samples from three students who represent the diversity and challenge in their class. The third Entry, Analysis and Action, provides an opportunity to for teachers to reflect on their professional lives. The first reflection is on the instructional sequence described in Entry II, the second is on themselves as beginning teachers, and the third on professional relationships (See Appendix B).

The Science Portfolio Development Handbook went through three rounds of full revision as well as numerous minor adjustments. Fifty-five science teachers completed portfolios using this Handbook.

The prime issue that remains is about how much information teachers need to provide in their portfolios. The tension is between having enough information for the scorers to make a judgement in which they have confidence and the amount of information required of already busy science teachers.

I believe the primary lesson learned is about portfolios. The INTASC Science group spent almost four years in the thoughtful design of a portfolio development process aligned with standards. Still, there are places I would change. Further this portfolio is one component of a series of assessments. However, schools, districts, states and teacher education programs are introducing portfolios as if they were a solution to all education problems. Portfolios, as all modes of assessment, have strengths and weaknesses. A science education reform system built on technical rather than substantive portfolios may not survive, I fear.

Evaluation

During the initial year of the portfolio development, seven courageous teachers completed a portfolio on the first draft of the Science Portfolio Development Handbook. These smoke-test portfolios allowed us to begin the development of a criterion-based portfolio scoring system. The Evaluation Procedure is configured around six Scoring Categories that are aligned with the INTACS Core Principles and the INTASC Science Standards. INTASC chose to develop a scoring procedure that relies on the professional judgement of trained scorers, is holistic and is hermeneutic. That means that the entire portfolio is the unit of analysis and that scorers work in pairs during the scoring procedure. Each of the Scoring Categories has three Guiding Questions, which are the organizing structures of the Evaluation Procedure. The three-stages of the evaluation procedure provide a disciplined approach to sampling and reduction of information about teaching. The amount of professional judgement increases with each stage. The first stage is notetaking. Using the 18 Guiding Questions (See Appendix C), scorers review and take notes on each part of the portfolio. In the second stage, using these notes, the scorers prepare a Summary Statement that includes information on each of the Guiding Questions. The scorers working in pairs then compare their individual Summary Statements and prepare a joint Summary. In the third stage, again working alone, the scorers use the Summary Statement and the rubric to make a judgement about the performance in the portfolio (See Appendix D). The rubric is organized around four performance levels for each Guiding Question. The rubric is marked first for each Guiding Question and then on the portfolio as a whole. The pairs of scorers again compare the scores they arrived at individually and prepare a final score with a justification. Members of the portfolio development committee helped refine the scoring system and served as mentors to new portfolio scorers.

There have been portfolio scorer training sessions ranging from 1 hour to fifteen days. Portfolio scorer training includes becoming intimately familiar with the standards and the handbook, learning to locate evidence in the portfolio, learning to take notes and to write a summary that is both succinct, informative and evidence based, applying the rubric and making a judgement based on the standards and the evidence in the portfolio. Training also includes recognizing personal biases, experience with a range of performances in the portfolios and developing speed and confidence. In addition to the members of the committee who helped design the scoring system and training, teams of teachers and teacher educators spent summers scoring portfolios developed under an increasingly refined handbook using an increasingly refined scoring system.

Four major issues remain about the evaluation procedure. The first is that the procedure requires learning to score in a way that distinguishes between the intuitions of an experienced teacher and matching evidence with standards. The second is that the scoring procedure is time intensive and thus expensive. There are many ways this time intensive procedure might be reduced. The question is at what point are the benefits of a performance assessment system with professional judgement sacrificed for efficiency. The third issue is feedback. There was not a single committee meeting, scoring institute, academy or training event at which the issue of feedback was not discussed. Experienced teachers and teacher educators wanted to share information about the performance with the beginning science teachers. This was true whether the score was high, typical or low. The final issues are around validity and reliability. Is a good portfolio score a valid indicator of good teaching? While several research projects were initiated to examine this issue, they have been slow, costly and inconclusive. If a different pair of scorers scored a given portfolio, would the final score be the same? Not surprisingly, increased training increases reliability.

Final Thoughts

One final task for INATSC Science was the preparation of a linking paper that provides a basis for legal challenges. In this paper, the Standards, the Handbook, the evaluation procedure and the rubric are compared. While many links are clear, it would improve the power of the system if there were an opportunity to revise the each of its components one more time. (See Appendix E.)

The INTASC Science Project was located at the intersection of policy, science teaching, and performance assessment. The project was influenced by and in turn can inform research and practice in each of these areas. Three years ago, interest in portfolios had begun to wane among INTASC members as the focus shifted to standards-based teacher preparation and alternate routes for teacher certification. Just last week, there was a request by INTASC for more information on portfolios. While the request seemed to be for a completed, quick, easy inexpensive portfolio process that could be adopted, what was offered was a portfolio design workshop. We'll see what happens.

From my work with INTASC Over the past six years, I will share three lessons I have learned. Once again I am reminded of the advantages and disadvantages of work completed by paid volunteers. One advantage is that the persons engaged in the INTASC science were in the midst of teaching science and/or teaching science teachers; one disadvantage was that everyone doing the work had multiple obligations. I also learned, again, the need for precise and well-defined language, coupled with the lesson that, no matter how clear I believe the communications are, they are always subject to interpretation. I am reminded of a dilution factor that results in decreased accuracy as information is passed from group to group. Finally, is my increased awareness of the competing values and priorities of a national education policy, policies of 50 states plus territories, universities, teacher preparation programs, classroom practice and science education research. When INTASC Science began, echoes of the teacher as professional were still resounding. Today there is less consensus about who should teach science and what qualifications or qualities these teachers should have. In the game of teaching and teacher preparation there are new players and old players have assumed new roles. The future is not clear. Currently we have the opportunity to determine answers to such questions as what is the role of the university in teacher preparation, the role of the school, the role of the state.

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Appendix A.

The INTASC Core Principles

The ten principles that comprise INTASC's common core of teaching knowledge and skills delineate what teachers should know and be able to do.

1. The teacher understands the central concepts, tools of inquiry and structures of the discipline(s) he or she teachers and can create learning experiences that make these aspects of subject matter meaningful for students.

2. The teacher understands how children learn and develop, and can provide learning opportunities that support their intellectual, social, and personal development.

3. The teacher understands how students differ in their approaches to learning and creates instructional opportunities that are adapted to diverse learners.

4. The teacher understands and uses a variety of instructional strategies to encourage students' development of critical thinking, problem solving, and performance skills.

5. The teacher uses an understanding of individual and group motivation and behavior to create a learning environment that encourages positive social interaction, active engagement in learning and self-motivation.

6. The teacher uses knowledge of effective verbal, nonverbal, and media communication techniques to foster active inquiry, collaboration, and supportive interaction in the classroom.

7. The teacher plans instruction based upon knowledge of subject matter, students, the community, and curriculum goals.

8. The teacher understands and uses formal and informal assessment strategies to evaluate and ensure the continuous intellectual, social and physical development of the learner.

9. The teacher is a reflective practitioner who continually evaluates the effects of his/her choices and actions on others (students, parents, and other professionals in the learning community) and who actively seeks out opportunities to grow professionally.

10. The teacher fosters relationships with school colleagues, parents, and agencies in the larger community to support students' learning and well-being.

Appendix B

Portfolio Development Handbook

Entry I: Setting the Stage
  - A. Teaching Context
  - B. Instructional Focus

Entry II: Instructional Design and Implementation
  - A. Daily Instruction and Student Learning
  - B. Featured Lessons
    - 1. Focus on Science Understanding
    - 2. Focus on Scientific Inquiry
  - C. Student Work

Entry III: Analysis and Action
  - A. Commentary on the Instructional Sequence
  - B. Commentary and Action Plan
  - C. Professional Relationships

Appendix C

Science Portfolio Evaluation Framework

I. Science Content and Student Learning. This category captures the teachers understanding of science ideas, scientific inquiry, and the application of science and how they have transformed their understanding to provide opportunities for all students to understand and do science.

I.1. What goals does the teacher develop for this instructional sequence so that students attain understanding of important science content?

I.2. What does the teacher do to ensure that all students attain understanding of science? (Highlighted students serve as indicators of attention to all students.

I.3. What does the teacher do to ensure that the science content is accurate, appropriate, logical and consistent.

II. Activities. This category captures how the abilities, interests, development and background of the students being taught are considered across the design and implementation of a variety of coherent modes of instruction. Activities are the investigations, demonstrations, projects, questions, problems, applications, and exercises in which students engage. Activities provide the intellectual contexts for students' development of understanding and ability in science.

II.1. In what kinds of science activities does the teacher engage the students?

II.2. In what ways are the activities appropriate for the instructional goals?

II.3. In what ways are the activities appropriate for the students?

III. Discourse. This category captures how the teacher engages in many forms of communication that support science understanding and science inquiry. Discourse refers to all the forms of communication in which the teacher and students engage. Discourse includes the ways of talking, writing, thinking, representing, agreeing and disagreeing that the teacher and students use as they engage in activities. The discourse embeds fundamental values about knowledge—about what makes an answer acceptable and what counts as legitimate science activities, arguments, and thinking. Teachers, through the ways in which they orchestrate discourse, convey messages about whose knowledge and ways of thinking and knowing are valued, who is considered able to contribute, and who has status in the group.

III.1. What kinds of thinking predominate in the oral and written discourse of the classroom?.

III.2. What is the teacher's role in fostering the oral and written discourse in the classroom?

III.3. What are the students' roles in fostering the oral and written discourse in the classroom?

IV. Learning Environment. This category captures how well teachers are able to maintain classroom learning environment in which students have safe opportunities to come to understand science through inquiry. It is the unique interplay of physical, intellectual, and social characteristics that shape the ways of knowing and working that are encouraged and expected in the classroom. The learning environment is the context in which the activity and discourse are embedded. Learning environment also refers to the use of materials and space.

IV.1. In what ways does the teacher manage the physical aspects of the classroom?
IV.2. In what ways does the teacher promote safety in the science classroom?
IV.3. In what ways does the teacher manage the social and psychological aspects of the classroom?

V. Student Achievement. This category captures how well teachers use various modes of assessment to allow all students to demonstrate that they have come to understand and are able to do science
V.1. In what ways does the teacher assess students' learning?
V.2. In what ways does the teacher communicate about formal and informal assessments?
V.3. Have the students achieved the goals of learning science provided by this instructional sequence?

VI. Life-Long Learner. This category captures how teachers use their experiences as a teacher, a learner and a member of the community to modify their instruction to increase support of student understanding of science. It includes the systematic reflection in which teachers engage and the plans that follow from this reflection. It entails the ongoing monitoring of classroom life—how well the activities, discourse, and environment foster the students understanding and ability of science. Through this process teachers examine relationships between what they and their students are doing and what students are learning.
VI.1. In what ways does the teacher learn from his or her teaching?
VI.2. In what ways does the teacher plan to improve his or her teaching?
VI.3. In what ways is the teacher a member of a learning community?

Appendix D

Sample of Rubric

I. Science Content and Student Learning. This category captures the teachers understanding of science ideas, scientific inquiry, and the application of science and how they have transformed their understanding to provide opportunities for all students to understand and do science. (INTASC Core Principles 1, 2 & 7)

I.1. What goals does the teacher develop for this instructional sequence so that students attain understanding of important science content?

4. Teacher sets goals for students to understand important, accurate science ideas, participate in aspects of scientific inquiry and engage in the applications science.
3. Teacher sets goals for students to understand important, accurate science ideas and either participate in aspects of scientific inquiry or engage in applications of science.
2. Teacher sets goals for students to understand science as vocabulary or "rhetoric of conclusions," participate in laboratory activities that confirm these conclusions and experience few applications of science.
1. Teacher sets goals for students to learn science as vocabulary with few, if any, laboratory experiences or opportunities for application.

Appendix E

Sample of Linkages

Scoring Category	**Associated Standards**	**Opportunities from Portfolio Development Handbook**	**Guiding Questions for Scoring**	**Rubric to inform evaluation**
Science Content and Student Learning. This dimension captures the teachers understanding of science **ideas,** scientific **inquiry**, and the **application** of science and how they have transformed their understanding to provide opportunities for **all students** to understand and do science.	1. The teacher of science understands the central **concepts,** tools of **inquiry**, **applications,** structures of science and of the science disciplines (physics, chemistry, biology and Earth and space science) he or she teaches and can create learning experiences that make these aspects of content meaningful to students. 2. The teacher of science understands how **students** learn and develop, and can provide learning opportunities that support their intellectual, social and personal development. 7. The teacher of science **plans instruction** based upon **knowledge of subject matter, students,** the community, and curriculum goals.	**From Contexts** **From Instructional Focus** **What are the overall goals for science learning in this course? What are the goals for this instructional sequence? How is the instructional sequence cohesive?** **From Lesson Log** **From Feature Lesson** **From student work samples** **From Analysis and Action**	I.1 What goals does the teacher develop for this instructional sequence so that students attain understanding of **important science content**?	*4. Teacher sets goals for students to understand important, accurate science ideas, participate in aspects of scientific inquiry and engage in the applications science.* *3. Teacher sets goals for students to understand important, accurate science ideas and either participate in aspects of scientific inquiry or engage in applications of science.* *2. Teacher sets goals for students to understand science as vocabulary or "rhetoric of conclusions," participate in laboratory activities that confirm these conclusions and experience few applications of science.* *1. Teacher sets goals for students to learn science as vocabulary with few, if any, laboratory experiences or opportunities for application.*

Appendix A.

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3. The teacher understands how students differ in their approaches to learning and creates instructional opportunities that are adapted to diverse learners.

4. The teacher understands and uses a variety of instructional strategies to encourage students' development of critical thinking, problem solving, and performance skills.

5. The teacher uses an understanding of individual and group motivation and behavior to create a learning environment that encourages positive social interaction, active engagement in learning and self-motivation.

6. The teacher uses knowledge of effective verbal, nonverbal, and media communication techniques to foster active inquiry, collaboration, and supportive interaction in the classroom.

7. The teacher plans instruction based upon knowledge of subject matter, students, the community, and curriculum goals.

8. The teacher understands and uses formal and informal assessment strategies to evaluate and ensure the continuous intellectual, social and physical development of the learner.

9. The teacher is a reflective practitioner who continually evaluates the effects of his/her choices and actions on others (students, parents, and other professionals in the learning community) and who actively seeks out opportunities to grow professionally.

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    - B. Featured Lessons
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        - 2. Focus on Scientific Inquiry
    - C. Student Work
- Entry III: Analysis and Action
    - A. Commentary on the Instructional Sequence
    - B. Commentary and Action Plan
    - C. Professional Relationships

Appendix C

Science Portfolio Evaluation Framework

I. Science Content and Student Learning. This category captures the teachers understanding of science ideas, scientific inquiry, and the application of science and how they have transformed their understanding to provide opportunities for all students to understand and do science.

I.1. What goals does the teacher develop for this instructional sequence so that students attain understanding of important science content?

I.2. What does the teacher do to ensure that all students attain understanding of science? (Highlighted students serve as indicators of attention to all students.

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VI.1. In what ways does the teacher learn from his or her teaching?
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Appendix D

Sample of Rubric

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3. Teacher sets goals for students to understand important, accurate science ideas and either participate in aspects of scientific inquiry or engage in applications of science.
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1. Teacher sets goals for students to learn science as vocabulary with few, if any, laboratory experiences or opportunities for application.

Appendix E

Sample of Linkages

Scoring Category	**Associated Standards**	**Opportunities from Portfolio Development Handbook**	**Guiding Questions for Scoring**	**Rubric to inform evaluation**
Science Content and Student Learning. This dimension captures the teachers understanding of science **ideas,** scientific **inquiry**, and the **application** of science and how they have transformed their understanding to provide opportunities for **all students** to understand and do science.	1. The teacher of science understands the central **concepts,** tools of **inquiry**, **applications,** structures of science and of the science disciplines (physics, chemistry, biology and Earth and space science) he or she teaches and can create learning experiences that make these aspects of content meaningful to students. 2. The teacher of science understands how **students** learn and develop, and can provide learning opportunities that support their intellectual, social and personal development. 7. The teacher of science **plans instruction** based upon **knowledge of subject matter, students,** the community, and curriculum goals.	**From Contexts** **From Instructional Focus** **What are the overall goals for science learning in this course?** **What are the goals for this instructional sequence?** **How is the instructional sequence cohesive?** **From Lesson Log** **From Feature Lesson** **From student work samples** **From Analysis and Action**	I.1 What goals does the teacher develop for this instructional sequence so that students attain understanding of **important science content**?	*4. Teacher sets goals for students to understand important, accurate science ideas, participate in aspects of scientific inquiry and engage in the applications science.* *3. Teacher sets goals for students to understand important, accurate science ideas and either participate in aspects of scientific inquiry or engage in applications of science.* *2. Teacher sets goals for students to understand science as vocabulary or "rhetoric of conclusions," participate in laboratory activities that confirm these conclusions and experience few applications of science.* *1. Teacher sets goals for students to learn science as vocabulary with few, if any, laboratory experiences or opportunities for application.*

A FOCUS FOR COLLABORATION: DEVELOPING AND IMPLEMENTING SCIENCE AND MATHEMATICS PERFORMANCE ASSESSMENT TASKS

J. Morrison, Washington State University
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According to national and state reform efforts in science and mathematics education (National Council of Teachers of Mathematics [NCTM], 2000; National Research Council [NRC], 1996), new forms of collaboration to foster integrated professional development for teachers are needed. These collaborations are seen as a means to involve practitioners and theoreticians in teacher education. Due to the participation of many players, collaborative efforts in teacher education draw upon a wide field of expertise, experiences, and perspectives. This paper describes a collaboration formed between university researchers, practicing teachers, and personnel from the local educational service district. This collaboration was formed to focus on increasing preservice and inservice teachers' understanding and use of performance assessment through a field based experience in K-8 mathematics and science methods courses.

Performance Assessment

Science and mathematics reform efforts (American Association for the Advancement of Science [AAAS], 1993; NCTM, 2000; NRC, 1996) have called for students becoming more involved in their own learning based on the philosophy that student understanding is facilitated by active involvement. The science and mathematics reforms have required students to not only answer questions accurately but to explain the process they used to derive their response. Performance assessment has been recommended to assess students' understanding of concepts in science (Shymansky, Chidsey, Henriquez, Enger, Yore, Wolfe, & Jorgensen, 1997). Well designed assessment tasks not only assess student understanding but teach concepts and require students to explain and communicate their solutions (Darling-Hammond & Falk, 1997; Shepard, 2000). Performance assessment is well-suited to this purpose because of its focus on the application of knowledge in an authentic context for an authentic purpose. Kelly and Kahle (1999) found that science students who took performance assessment tests were better able to explain their reasoning and conceptions than students who took traditional tests, leading to the conclusion that they had stronger understandings as a result of working through the performance task. When studying the effects of classroom based performance assessment-driven mathematics instruction, Fuchs, Fuchs, Karns, and Katzaroff (1999) found that students in performance assessment-driven instruction classes demonstrated stronger problem solving skills than comparison groups that were not performance assessment-driven. Borko, Mayfield, Marion, Flexer, and Cumbro (1997), in a study of a professional development program which stressed using performance assessment strategies in mathematics instruction, found that teachers changed their instructional practices to incorporate using more problem solving activities, requiring student explanations of strategies, and using rubrics for assessment of open-ended tasks. Thus, implementing performance assessment in mathematics and science classrooms appeared to be a promising approach both for preservice teachers' learning and inservice teachers' professional growth.

Field-based Experience

In this collaborative project, the emphasis was on the development of preservice teachers' understanding and ability to implement performance assessment in the classroom. To that end, this project focused on a field-based experience for preservice teachers enrolled in a K-8 science or mathematics methods course.

Both educational researchers and students bound for a teaching career agree that there is a need for more direct, specific, and practical experiences in classrooms prior to student teaching (Anderson & Mitchener, 1994; NRC, 1996). Field experiences early on in the teacher training have a lasting effect. Schoon and Sandoval (1997) indicate that more "real-world" opportunities for preservice teachers to practice their skills will help them gain necessary skills faster. Borko, et al. (1997) emphasize the importance of situating preservice teacher learning in classroom practice. Putnam and Borko (2000) argue that for teachers to construct new knowledge about their practice, the learning needs to be situated in authentic contexts. Preservice teachers need a combination of university learning for theoretical foundations and school-based learning for a situated perspective. Spector (1999) recommends having preservice teachers work with inservice teachers to help them better apply newly learned teaching and assessment strategies. This finding is in line with Dickinson, Burns, Hagen, and Locker's (1997) finding that important changes in science teaching can take place with the support of an enthusiastic peer.

As well as providing valuable experiences for preservice teachers, field-based experiences are beneficial for the inservice teachers who are involved in mentoring the preservice teachers. The inservice teachers are exposed to new strategies and techniques, share their own strategies and techniques, and collaborate in the evaluation of student work. Learning experiences for both preservice and inservice teachers must include inquiries into the difficulties and questions teachers regularly face (NRC, 1996). It is essential that teachers, both preservice and inservice, have opportunities to observe, practice, and evaluate appropriate assessment tasks. The National Science Education Standards (NRC, 1996) discuss the need for teachers to be involved in the design and implementation of assessment.

> Teachers must have opportunities to observe practitioners of good classroom assessment and to review critically assessment instruments and their use. They need to have structured opportunities in aligning curriculum and assessment, in selecting and developing appropriate assessment tasks, and in analyzing and interpreting the gathered information. Teachers also need to have opportunities to collaborate with other teachers to evaluate student work-developing, refining, and applying criteria for evaluation. (p. 67)

Goals

The goals of this project were to introduce preservice teachers to performance assessment through its development and implementation and to increase the understanding of performance assessment tasks in practicing teachers. Providing the preservice teachers with a chance to be in their mentor's classroom observing students and actually implementing their performance assessment task was a high priority of this project. A secondary goal was to establish a collaborative partnership between university science and mathematics methods instructors, the local educational service district personnel, and inservice teachers from local school districts.

Collaborative Partners

The collaboration between Washington State University-TriCities (WSU-TC), the Educational Service District 123 (ESD), and teachers from six local school districts in southeastern Washington state was the backbone of this project. The partners had specific roles and objectives in the project. Two university faculty, one mathematics and one science educator, were each responsible for developing a methods course that incorporated a performance assessment sector in which preservice teachers were introduced to performance assessment, designed a performance assessment task, received feedback from the instructor, and then implemented the task. The university faculty collected data on all aspects of the preservice teachers' thinking and written projects. The ESD math/science specialist was responsible for selecting mentor teachers, providing them with information on performance assessment, and communicating with the teachers as the project progressed. The mentor teachers were paid a stipend ($150 per semester) for their time through external funding received and administered by the ESD. The ESD partner set up formal meetings between the preservice and inservice teachers. All communication with the mentor teachers was done by the ESD staff, this included a survey on their understanding of performance assessment, the rating of the preservice teachers' implementations of the tasks, and their feedback on the overall project. This involvement of the ESD partner was a key factor in the project because there was no field component required for the methods classes and no faculty at the university to handle field placements.

The two university faculty members and ESD math/science specialist were the primary collaborators in this project with the inservice teachers playing a more secondary role. They did not attend the planning meetings or take part in the development of the project. The inservice teachers were responsible for mentoring the preservice teachers as they developed a performance assessment task. This mentoring took place at an initial meeting of all participants and through phone or e-mail communications. The inservice teachers also provided the classroom where the task was implemented and gave feedback at the completion of the performance assessment task in their classroom.

Program Description

This project initially began during the spring semester of the 2000 school year. Three teacher leaders were selected to work with a university mathematics educator on performance assessment tasks. These teachers mentored 10 preservice teachers as they developed a mathematics performance assessment task. The task was then implemented in the mentor teachers' classrooms. During the fall semester of 2000, 19 preservice teachers from a science methods class and 10 mentor inservice teachers were involved in the project. The preservice teachers developed a performance assessment task and received feedback from their science methods instructor and their mentor teacher. As these semesters did not involve all the collaborative elements in place during the spring semester of 2001, they will not be discussed in depth; however it is important to stress that the foundations for this collaboration developed from the onset of the project. The collaborative partnership that was established in November, 2000, will be the focus of this paper.

By January of 2001, a group of 54 preservice teachers, enrolled in either a science or mathematics methods course, and 25 mentor teachers selected by the ESD were ready to begin the project. Some of the preservice teachers in this group had already participated in the project during their fall science methods course, involving them in a second performance assessment task experience added depth to our conclusions. The mentor teachers were selected from a list of recommended teachers; the list was comprised of exemplary science and mathematics teachers from eight school districts in the area around the university. After agreeing to participate, the mentor teachers were sent a packet of information on performance assessment and attended an introductory meeting at the university.

Prior to beginning their science or mathematics methods class, the preservice teachers were surveyed and interviewed on their views and understanding of performance assessment. The preservice teachers were then given in-depth instruction on designing and implementing performance assessment tasks. After lengthy collaboration between the preservice teacher and their mentor, a science, mathematics, or combined science and mathematics performance assessment task was developed.

The preservice teachers worked either individually or in pairs on the performance assessment project but each student was required to complete three parts of the assignment. The first part involved reviewing a minimum of two journal articles on their topic to gain an understanding of the teaching and learning issues surrounding their topic. The preservice teachers also were asked to complete a plan for their performance assessment task. The second part of the assignment involved of an overview of the task, references used in development of the task, alignment of the task with state/national standards, special instructions, and any materials needed for the implementation of the task. A copy of the task as it would be administered to students and the scoring rubric were also included in this part of the assignment. After the task was taught in the classroom, the preservice teacher turned in a final draft of the task as it was presented to students, the final rubric, and any mentor teacher comments that were given. Samples of scored student work were included as were analyses of students' understanding based on their performance on the task. Also included in this section were reflections, implications, and suggestions for the improvement of the task. In addition, the preservice teachers provided reflections on their collaboration with their mentor.

The preservice teachers were videotaped implementing their performance assessment tasks in the classrooms by their mentor teachers or another project partner. After implementation of the task, the preservice teachers were interviewed a second time and again completed the survey of their understanding of performance assessment. The mentor teachers filled out a survey on their views of performance assessment, the performance assessment task implemented in their classroom, the mentoring process, and the overall project.

Throughout the project, the university faculty and the ESD math/science specialist met regularly to determine the progress of the project. These meetings were held weekly for the first two months of the project and then bimonthly for the remainder of the project. Typically the meetings lasted two hours and involved discussions on the progress of the overall project and specific individual concerns and frustrations about the preservice teachers, inservice teachers, or performance assessment tasks. The two university partners and the ESD partner all communicated via e-mail and phone conversations regularly throughout the project, often every day. To ensure that all conflicts and concerns were aired and addressed, the main partners in the collaboration felt it was necessary to communicate openly and consistently.

One of the major jobs of the partnership was to pair the preservice teachers with the inservice mentor teachers. The university faculty knew the preservice teachers, the ESD member knew the inservice teachers. This pairing required lengthy discussion of the characteristics of all participants and the ultimate establishment of a single or pair of preservice teachers matched with a mentor teacher who would be most compatible with them. Other activities the partnership was involved in consisted of setting up inservice/preservice teacher meetings, interviewing participants, videotaping preservice teachers, reviewing performance assessment tasks, and planning for future projects.

Program Evaluation

Both the strengths and weaknesses of the project were evaluated. The success of the collaboration was based on a variety of aspects. The primary goal of the project was to positively affect teachers' understanding of performance assessment through implementation in a field-based situation. The secondary goal was to establish a collaborative partnership between university science and mathematics methods instructors, the local educational service district personnel, and inservice teachers from local school districts.

Understanding of Performance Assessment

Prior to intervention, the preservice teachers had very little understanding of performance assessment as indicated by low scores on the coding scheme used (Fuchs et al, 1999) to score the surveys and interviews. Initially, examples given by preservice teachers included very few of the components necessary to a performance assessment task: their examples tended to be short, required single answers, and did not provide opportunities for their students to generate ideas. Additionally, none of the preservice teachers said they would require students to explain their work or provide a written communication about their work when doing a performance assessment task. Their ideas of performance assessment were not couched in an authentic task.

Following the design and implementation of their task, the preservice teachers' understanding of performance assessment improved greatly. Analysis of the data show that the preservice teachers did come to understand assessment as a formative process, they also constructed ideas of what performance assessment is, when it is useful, and when it is not appropriate. All preservice teachers required from their students written explanation of strategies, modeling of strategies, and multiple questions that required application of knowledge set in an authentic context. The preservice teachers provided substantive analyses and interpretations of students' thinking, understandings, and lack of understandings. The following quotes represent two of the preservice teachers' views of performance assessment after the performance assessment task implementation (May, 2001).

> ...performance assessment is a task which has a real world problem to assess students' understanding of a topic. It is most appropriate to assess what someone already knows, like at the beginning to see what someone already knows about it, or at the end to evaluate what they have learned and how your teaching has helped them to understand that concept. (Tara, post-interview)

> Performance assessment I would define as sort of an assessment project that engages the students to use all they have learned to solve a problem that kind of involves all they know. (Karin, post-interview)

Analysis of the mentors' responses on the surveys showed that they learned more about performance assessment strategies and gained ideas for their own teaching through their involvement in the project. The majority of the mentor teachers had had some professional development on performance assessment in the past; all but seven said that they learned something new from this project. The mentor teachers expressed the following quotes on the surveys collected in May, 2001.

> Having not had much experience w/design of PA (performance assessment), I learned a great deal about how to focus the task and clarify it for students. (Paul, survey)
>
> This task also helped me see that I need to do more assessment tasks frequently and expect more writing out of them (students). (Ann, survey)
>
> I saw the breadth of concepts that could be integrated in one task. I saw the students enthusiasm for each project and I saw the processing of information and the problem solving taking place in each group. (Carol, survey)

Field-based Experience

The situated nature of the project (i.e. designing a task for actual students, working with an experienced teacher, and administering the task in a school classroom) seemed to be the most important factor in solidifying the preservice teachers' interest in and learning from the project. The preservice teachers felt that the field experience was beneficial to their training, for many of them this was the first time they had taught a lesson in a "real" classroom. The quotes of the preservice teachers that follow were expressed on a survey administered in the fall of 2001.

> It was a nice safe way to teach a lesson for the first time. If it bombed, I didn't have to go back and face everyone, but I could still learn from it. (Ginny, post-project survey)
>
> The experience overall was very good…Simply working with real students as well as designing and implementing a performance task. (Roy, post-project survey)
>
> I needed the classroom experience. It was exciting to see the kids working on this. (Beth, post-project survey)

> This project was an excellent opportunity to work with an actual math class. It gave me a good picture of what the students know and how they can learn. (Karin, post-project survey)

The preservice teachers felt that the mentoring they received from the inservice teachers was extremely beneficial. They met personally, e-mailed, or talked on the phone with their mentors as they worked on designing their performance assessment tasks. The inservice teachers successfully provided the preservice teachers with information on the students they would be teaching, the school situation, and the time they could use for implementation of the task. The main complaint that was expressed by the preservice teachers was that the inservice teachers did not provide adequate feedback after the implementation of the performance assessment task.

> I would have liked to have written feedback. Perhaps on a few pre-ordained questions. (Dana, post-project survey)

> It would have been nice to even get some constructive criticism (she may not have felt comfortable doing that). (Carol, post-project survey)

The lack of adequate feedback from mentor teachers to the preservice teachers after the implementation of the task was seen as one of the weaknesses of the project. In the description of their duties as a mentor, the mentor teachers were asked to "provide feedback on the implementation of the performance assessment task in the classroom" to the preservice teachers. It was seen by the preservice and inservice responses that more specific directions needed to be given to the inservice teachers on how much and what type of feedback to provide.

Many of the preservice teachers were frustrated when they attempted to schedule meetings or receive feedback from their mentors. They had difficulty understanding just how busy a full-time teacher is. The preservice teachers also were frustrated by the mentors' lack of understanding of performance assessment and the large amount of time necessary to administer their tasks.

The situated nature of the project also provided a learning opportunity for the inservice teachers. The majority of the inservice teachers ranked the success of the project as high and mentioned that observing their students being taught by the preservice teachers had given them more information about their students and was very helpful to them. The inservice teachers provided the following quotes on the survey they took in May, 2001, at the end of the project.

> It (performance assessment task) showed me at what level they (students) are at on measurement. (Pat, survey)
>
> I learned a great deal about kids number sense and I did use what I saw as areas they struggled with as the focus of a few math lessons. (Kate, survey)
>
> They (preservice teachers) were both tentative about taking charge of the task but the performance assessment had such a high interest level that students were interested in getting started. (Dale, survey)

The inservice teachers' awareness of what preservice teachers are required to do in their university science and mathematics methods classes increased through participation in this project. When asked what they perceived as a strength(s) of this performance assessment project, many expressed delight at the quality projects that the preservice teachers produced. The inservice teachers also felt they benefited from their participation in this project through strengthening their mentoring skills.

> Working with a "new" person, I learned you really have to focus your area of study. (Fran, survey)
>
> It affirmed my strong belief in observable assessment for young learners.
> It gave me a chance to teach someone else techniques I have developed. (Kim, survey)

One frustration expressed by the inservice teachers was the preservice teachers' lack of knowledge about student learning and classroom control. They seemed more confident with providing feedback on the classroom management abilities of the preservice teachers than providing comments on aspects of the performance assessment task implementation.

> Her preparation was very thorough. She tried to give good comprehensive directions but never stopped to monitor if the kids understood her. (35 minutes of straight directions!) The kids did not understand the concept or what Cari wanted. (Gail, survey)

> The lesson went fairly well. The lesson was well planned and the content was excellent. The lesson lacked effectiveness in the delivery and management. (Tara, survey)

The science and mathematics educators at the university felt that the field based aspect of the project was successful. Being able to include a field based experience for their methods students was a benefit of the project as no field component had been involved in either methods course prior to this project. Moreover, the experience was one that truly situated the learning goals of the methods classes in the schools overcoming the challenge discussed by Putnam and Borko (2000) of field placements that are inconsistent with learning goals. The university faculty members reflected on the project as follows:

> I felt good that this gave the students the opportunity to do a field based experience that encouraged them to focus on reform issues in science and math. (Science educator)

> This project met my goals for providing a field based experience for preservice teachers. The one comment I heard over and over from the preservice teachers was that regardless of any logistical issues, challenges, it was one of the best experiences they had in the program because they had a chance to go out into the schools and experience the type of teaching and learning we talk about in the methods class. (Math educator)

> My sense is that the performance assessment task was one way to really ensure they (preservice teachers) just weren't going into the schools and teaching in the old, traditional way. I don't think performance assessment is the only way to do that, but it is one way to ensure that mentor teachers don't just give them something to do in the classroom that isn't particularly meaningful and isn't consistent with our reform based goals. (Math educator)

The math/science specialist from the ESD viewed the field experience portion of the project from a differing perspective. The inservice teachers were asked to provide mentoring for a small stipend and also asked to allow an inexperienced preservice teacher into their room to work with their students. The reflections of the ESD partner on the field experience follow:

> It was amazing how supportive and welcoming the inservice teachers were to the preservice teachers. Many (inservice teachers) commented on how important they knew it was to have a chance to get into a real classroom when learning to teach. A couple remarked that they wish they had had this kind of a chance when they were preservice teachers. (ESD math/science specialist)
>
> One of the difficulties was finding competent mentors to support the field based experience. We tried to be selective but found that many of the inservice teachers that are competent math or science teachers do not have the time or inclination to take on something more. (ESD math/science specialist)

Collaboration

A number of crucial problems with the collaboration were identified at the culmination of this project. These were areas that hindered the project to a certain extent although they did not affect the overall success.

Communication among all players is essential to an effective partnership. In this collaboration, it was helpful that university and ESD members met weekly at first and then bi-monthly for the remainder of the project. Establishing communication with the inservice teacher members was more problematic. Communication with the inservice teachers was difficult, they often took 3-4 days to respond to e-mails or failed to respond altogether. The inservice teachers were required to attend one meeting at the university; most were able to do this although three were not. The positive aspects of the required meeting at the university were that the inservice teachers met the university faculty and ESD personnel in person, had an initial planning meeting with the preservice teachers assigned to them, and made contact with other inservice teachers involved in the program. This meeting was essential to the planning process as all partners were active and participating in the task development simultaneously. It was also important to have the inservice teachers physically at the university; some of them had never been there before. The inservice teachers valued the planning meetings and expressed the need for more:

> It might have been helpful to have the mentors meet at the college with the students more than once. Also, a way to make sure the mentor and students are meeting on a regular basis. (Shelly, survey)
>
> I felt a need to meet more often with the preservice teachers. It was difficult to communicate efficiently by e-mail. (Kelly, survey*)*

It would have been valuable for the university or ESD personnel to meet with the inservice teachers personally or have direct communication with them weekly. This would have provided all partners more knowledge on the progress of the field experience and the inservice teachers would have felt more involved in the project. The inservice mentor teachers needed to be given very specific guidelines and expectations for their role as a partner in the project. For example, the inservice teachers were expected to provide feedback to the preservice teachers who implemented their performance assessment task in their classroom. Most of the mentors did not do an adequate job of this. The mentors were asked to provide feedback but were not given specifics as to how often, when, or what depth to go with the feedback.

A concern that was voiced by members of the partnership was the large amount of time necessary to carry out a project such as this. It took time to include the performance assessment project in the methods classes, time to communicate and meet with other partners, and large amounts of time to observe and provide feedback to the preservice teachers. The partnership as set up, depended upon the ESD partner to do much of the organization of the field experiences. Reflections from the university and ESD partners on the some of the logistical and time concerns follow:

> It would be important to find a way to resolve time issues and perhaps find a way to have this assignment a part of a separate assessment course. (Science educator)

> To make this type of project sustainable, we need the logistical support in planning and matching and some sort of liaison with what is happening at the university and what we need to have happen in the schools, and in this case, the ESD provided that link. If the ESD weren't providing the logistical support they provided, we would need some other form of staff support at the university for these placements. (Math educator)

> When collaborating on a project like this it seems like it is very difficult to get anything ironed out unless everyone is sitting down together at the same table. We did e-mail a lot and talked on the phone but the really effective communication happened when we were all together physically. (ESD math/science specialist)

Conclusions

One conclusion drawn from the evaluation of this project is that providing the preservice teachers with a field-based experience enriched with mentoring from an inservice teacher was valuable to the preservice teachers. Using performance assessment as a focus for this mentorship project emphasized alternative assessment and standards-based instruction and provided a common purpose for all participants. A dilemma science teacher educators face is whether or not field experiences have enough focus so that preservice teachers can practice the new approaches they are learning in their teacher education programs (Anderson, & Mitchener, 1994). This project's field experience for preservice teachers was focused on performance assessment and allowed preservice teachers time to design and implement a task of their own development.

A second conclusion is that the collaboration between the educational agency, the university, and the school districts was powerful and essential to the project as it was designed. The individual partners in the collaboration could not have carried out the project on their own. In order to instruct preservice teachers in performance assessment, organize and monitor the field experiences, recruit and communicate with mentor teachers, and provide classrooms and knowledge of specific contexts for the field based experience, all partners were necessary.

Recommendations

Based on our findings, recommendations will be made for projects similar to this in terms of using performance assessment in a field based experience and for projects attempting similar collaborations.

In order to adequately implement a performance assessment task in a field experience, it was seen that the preservice teachers needed to observe in the classroom prior to the implementation of the task, spend two to three days for implementation of the task, and then revisit the classroom with their results and to receive feedback. It is recommended that clear expectations be given to the mentor teachers on how much, what type, and when to provide feedback to the preservice teachers.

The expertise, experience, and training of the mentor inservice teachers is an important aspect of a field based, focused project such as this. It was difficult to find mentor teachers who were adequately trained to be mentors for performance assessment tasks in math and science. Even though the majority of the mentors said that they had had past training in performance assessment, all but seven mentioned that they did learn something new. It is recommended that very focused training be provided by the project members for participating mentor teachers. In this way, all members would be using the same terminology and understand the complexities of issues relating to assessment. It is also essential to spend the time and effort when recruiting mentor teachers to ensure that the teachers involved are the best available.

The following considerations and recommendations are made in order to form and sustain a strong collaboration and to succeed in a collaborative effort.

One possible solution to the lack of communication from inservice teachers might be to reimburse their time at a specific rate per hour and ask them to log all hours spent on the project.

If teachers feel that the project will reward them for all the time they are able to spend, they may feel more committed to their role. Another important aspect of inservice teachers' commitment to the project would be the value placed on the professional development they gain from participation in the project. They could be compensated with professional development or university credits so that they see value placed on their participation.

The funding of this project was limited by the amount of grant money available. If external funding had been greater, the mentor teachers could have been more adequately supported. In order to develop and provide continuity for a strong collaboration, external funding needs to be extensive and sustainable.

A number of factors hindered the continuation of this collaboration. The lack of external funding to provide stipends for the mentor teachers and a salary for the ESD math/science specialist was the major factor. Also, the change in personnel at both the university and ESD changed the make up of the collaborative partnership. In order for collaborations to maintain their viability and continue to be effective, a minimal amount of personnel turnover is needed.

Summary

This collaborative project was successful in providing a field based experience focused on performance assessment in math and science for preservice teachers. The project was able to positively affect both preservice and inservice teachers' understanding and experiences with performance assessment tasks. The mechanics of collaboration emphasized to all participants that partnerships are valuable and rewarding, although they cannot be sustained without adequate funding, low personnel turnover, and committed school district partners.

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VIEWS OF SCIENCE TEACHERS ONE-THREE YEARS AFTER A PRE-SERVICE INQUIRY-BASED RESEARCH COURSE

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The National Science Education Standards (National Research Council, 1996) and the Benchmarks for Science Literacy (AAAS, 1993) indicate the importance of science curriculum reform because of the need for all Americans to become scientifically literate. Project 2061 was started in 1985 by the American Association for the Advancement of Science (AAAS) in order to reform K-12 science, math, and technology education. The significance of the name Project 2061 is that Halley's comet was visible in 1985 when the project was started and the year 2061 is when the comet will return. It is the hope of the AAAS that all Americans will be scientifically literate by the year 2061.

The need for science education reform has been motivated by other factors than "liberating the human intellect" alone. For example, there is a shortage of qualified people to fill professional science positions including K-12 educators. Education studies in the United States conducted in the 1980's were initiated because of various public concerns. These concerns included economic decline and educational shortcomings such as low test scores and a low ranking in comparison to other advanced nations in students' knowledge of science and mathematics. According to some of the reports, the economic decline has been attributed to education failures (AAAS, 1990).

Science for all Americans (AAAS, 1990) states the belief that the science literate person:

> Is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses

> scientific knowledge and scientific ways of thinking for individual and social purposes. (p. xvii)

Schwartz, Lederman, and Crawford (2000) state that scientific literacy includes knowledge of scientific concepts (facts), scientific inquiry (processes), and the nature (values and assumptions) of science. They and other researchers (Melear, Goodlaxson, Warne, & Hickok, 2000; Duggan-Haas, 1998a) feel that the failure of Americans to reach scientific literacy can be attributed in part to a deficiency in learning by scientific inquiry and about the nature of science. Students and their teachers who have not had adequate experiences in conducting scientific inquiry may view science as nothing more than isolated facts that are difficult to apply to the real world.

Science literacy can only be accomplished by improving the training of our future K-12 science educators. Teachers must gain the necessary knowledge and skills through "authentic scientific inquiry experiences" provided throughout science teacher education (National Research Council, 1996). This can include an "immersion into the culture" of science by completing an undergraduate research experience within a course designed specifically for that purpose (Melear, et al., 2000). This study qualitatively examines the longitudinal effects of one such course offered at the University of Tennessee, Knoxville. This type of research is important because the results can be used to improve the quality of science teacher education.

Relevant Research/Theory Concerning Preservice Science Teachers' Research Experiences

In order to understand how to improve science education and scientific literacy an important place to start is to study how science teachers are prepared. The Salish I Research Project (Duggan-Haas, 1998a and Simmons, Emory, Carter, Coker, Finnegan, Crockett, Richardson, Yager, Craven, Tillotson, Brunkhorst, Twiest, Hossain, Gallagher, Duggan-Haas, Parker, Cajas, Alshannag, McGlamery, Krockover, Adams, Spector, LaPorta, James, Rearden, & Labuda, 1999) studied the entire system of science teacher preparation including the practices of beginning secondary science and math teachers. Salish I was conducted by a national research collaborative which extended over a three-year period. Participants came from nine university research sites. Several findings of the Salish I study have relevance to this research study. One important finding was that students preparing to be science teachers experience a clash between the culture of a science education classroom and a pure science classroom. Another finding was that there is a lack of appropriate research experiences provided for science education students in universities.

Dichotomy of Two Cultures

The Salish I study showed that there is a lack of coherence between the content area training by scientists and the teacher education course work by science educators within the science teacher education programs studied (Duggan-Haas, 1998b). The culture of the typical college science classroom is one in which the scientist instructor lectures, promotes competition and discourages collaboration. The culture of the science/teacher educator classroom requires collaboration and discourages competition in order to create a community of learners. Scientists within a college often do not see themselves as part of the process of educating scientifically literate citizens. Their courses are often structured to weed out students and can turn away potentially good candidates for teaching. Duggan-Haas (1998b) presents several possibilities to improve college teaching including, recognizing the difference in the two cultures, recognizing that scientists are teacher educators and they must be responsible for helping improve the situation, and encouraging potential teachers by structuring the courses for learning rather than selecting and weeding out.

Lack of Appropriate Research Experiences for Science Educators

Based on findings of the Salish I study, Duggan-Haas (1998a) stresses the importance that pre-service science teachers (those that are training to be teachers) can benefit from research experiences. Teachers who completed an undergraduate research experience (RE) had much better understandings of the nature and processes of science than teachers who had not had the experience. “The RE seems to change the world view of those who complete it. . . . . The research experience can trigger an epiphany about the nature of science” (p. 6). However, there are problems with the way that most colleges structure REs in science. They are designed for students who wish to become researchers in a particular field of science, not for preparing students to teach. The RE often leads to a specialty in an obscure area of science that cannot be easily adapted to the K-12 curriculum. Completing a RE can often be an “initiation into the culture of science” (p. 1); however, without proper guidance, teachers may inappropriately associate this affiliation with the style of teaching of the scientist in the science classes that they teach. This style, as discussed earlier, is predominantly exhibited by lectures, promoting competition, and discouraging collaboration.

REs can be structured to benefit teachers in the process of attaining scientific literacy in the following ways. “Make the experience an explicit model for teaching and learning and modify the experience so that it is more readily translatable to the secondary classroom” (Duggan-Haas, 1998a, p. 12). Investigations, which are adaptable to the K-12 curriculum, can be designed using the classroom as a research site “The nature of the eperience should be reflected on to help teacher candidates design parallel experiences for their own students” (Duggan-Haas, 1998a, p. 13). REs conducted in this manner can help pre-service teachers learn to be more inquiry-based and student-centered in their teaching which are some of the attributes teachers need to help promote scientific literacy.

An Attempt to Provide an Appropriate RE for Science Educators

Melear, a K-12 science education professor at the University of Tennessee, Knoxville, determined that most of the students who apply to the College of Education to become future science teachers have never actually conducted any authentic science (2000). The courses which included laboratories that these students completed as part of a major in a particular area of science typically did not include inquiry experiences in which they were a part of designing and carrying out their own experiments. She, along with Hickok, subsequently initiated a course called "Teaching Science-Just Do It" ("Do It") within the science department at the University to help alleviate the problem. The course is structured to allow pre-service biology majors to have REs that are designed for teachers to experience inquiry. "Many teachers come to learning activities with preconceptions about teaching science. At a minimum, their own science learning experiences have defined teaching for them" (National Research Council, 1996, p. 67). Therefore, if a teacher has not experienced learning as an inquiry process, it will most likely never be initiated in the classroom.

The theoretical foundations that Melear (2000) used for designing this course included immersion, the apprenticeship model for instruction, social constructivism, and situated cognition. Immersion is an approach to "teaching for thinking" in which pre-service teachers are immersed in the culture of science by conducting scientific research for a prolonged period in a lab. "Science can be considered as a culture, which can be learned best in the environment of members of that culture" (Melear, 2000, p. 7). The apprenticeship model for learning is the "acculturation into the world of the expert" (p. 8). The actual participation in the world of the "expert" is an important criteria to allow the "expert" to transmit knowledge to the "novice." This knowledge changes with different contexts. Social constructivism and situated cognition can be used to describe how pre-service science teachers can "construct new knowledge through social interactions" (Melear, 2000, p. 8) Melear (2000) suggests that "placing learners . . . into the culture of science (science laboratories) will create an immersion experience in the culture, especially if the aspiring teachers are surrounded by persons who practice that culture, i.e., persons who 'speak the language'" (p. 9).

Research

Context, Questions, Goals, and Rationale

Context

Longitudinal research is needed to investigate the effect of science teacher education programs. "The impact of the program may not be evident until 2 or 3 years after the experience" (Adams & Krockover, 1999, pp. 968-969). This type of research can also assist in planning "interventions and professional growth opportunities" (p. 969). Universities often do not take responsibility for tracking teacher graduates and determining the effectiveness of their training. To address the dearth of data, this study tracked graduates who received the inquiry course intervention, one-three years after completing the course. One of our goals was to track these teachers as they began teaching (Melear, 2000). If we can understand their responses to the course and if they use the inquiry methods advocated in the course in a way that promotes scientific literacy, other universities might be inclined to implement similar programs.

The course has been offered six semesters at the University of Tennessee, since 1997. The pre-service science teachers were encouraged to take the course as part of their undergraduate program in biology. At the University of Tennessee, prospective teachers complete a four-year undergraduate program within a major area and then complete a year-long teaching internship within a school near the university as part of a master's program. As stated earlier, the course is designed to provide research experiences for the biology teacher; therefore, all students who took the course had undergraduate biology concentrations.

Questions

Our objective was to identify how and if these teachers were influenced by the "Do It" course. Specific research questions included the following:

- Did the experiences the participants had with inquiry in the course help them understand how to teach by inquiry?
- Did the course help the participants understand the nature of science?
- How does the course compare to other courses the participants had in preparing them to teach?

Research Goals – A description of the qualitative philosophy of inquiry

In order to understand the meanings the course had for participants, a qualitative rather than quantitative approach was necessary. Studies in science education have traditionally "ignored the meanings that participants in a study bring to the experience rather that viewing these meanings as integral to the experience" (Simmons, et al., 1999, p. 932). Meanings are complex in that they are unique, shared, constantly changing, subjective, contextual, and created through interaction in our world. Qualitative research is "any systematic investigation that attempts to understand the meanings that things have for individuals from their own perspectives" (Singletary, 1994, p. 266). Whereas qualitative research is descriptive and collects data in the participants' own words, quantitative research is statistical and data is collected based on the researcher's predetermined agenda (Bogdan & Biklen, 1992).

Rationale

Individual interviews were conducted because they allowed the participants' perspectives to be expressed in their own words (Taylor & Bogdan, 1984). This method of qualitative research was appropriate for several reasons, including several issues related to time and the goals of the research. The first issue with time was that the first author did not observe the participants while they took the course. Therefore, asking them to describe the course personally, was an appropriate way to get at the meanings the course had for them.

Interviews were appropriate for the goals of the research as well. According to Taylor and Bogdan (1984), interviewing is well suited when "research interests are relatively clear and well-defined" (p. 80) and when the "researcher wants to illuminate subjective human experience" (p. 81). The goals of finding out the meanings of the "Do It" course were clear. Interviews are used when direct observations cannot be made. Patton (1990) suggests that feelings, thoughts, and intentions cannot be observed.

Methods

A qualitative study was chosen because the research questions suggested the use of such methods. Qualitative methods and analysis are emergent, meaning that the methods used to collect and analyze data can change throughout the study based upon what is discovered during the research. For example, questions on an interview guide can and should be changed after a study has begun, when issues emerge from the participant's feedback. Quantitative methods would require that questions asked of participants remain the same throughout the study.

Participants

Recruitment

Participants were recruited from a list of 13 students, who had taken the course in the Fall of '97, '98, or '99, and who were currently teaching. The students from the Fall of '97 were in their second year of teaching. The students from the Fall of '98 and '99 courses were in their first year of teaching. In order to recruit research candidates each was sent a letter by e-mail explaining the purposes of the study and asking them if they would be willing to participate. If there was no response to the e-mail letter, the same letter was mailed to their home address on. If there was no response to the mailed letter, the prospects were telephoned. Eight of the 13 possible candidates were contacted. The five that were not contacted had changed their mailing address since attending the university and did not respond to any e-mail attempts or phone calls (in two instances, a phone number was not available).

All eight candidates that were contacted agreed to be research participants. Only three out of the eight participants lived more than an hour out of the Knoxville, Tennessee area. Four of the participants were interviewed at the Tennessee Science Teachers Association (TSTA) conference between November 30-December 2, 2000 in Nashville, Tennessee. Two other participants were met at the University of Tennessee library for their interviews. One of the participants requested that the interview be held in her classroom after school. The final interview was conducted over the phone.

The number of participants for a study can vary; however, according to McCracken (1988), eight participants are an appropriate number to include in a qualitative study. A major factor in determining participant numbers is when information redundancy has been reached. For the purposes of this study eight were interviewed and data was examined to determine if a level of redundancy was reached. This level is reached if no new information is found in consecutive interviews. If new information had been found, additional participants would have been solicited.

Finally, the instructor and co-creator of the "Do It" course, Dr. Leslie G. Hickok was contacted in April 2001 for an interview by the first author. He agreed to an interview to discuss the course. It was important to use him as a data source as well. Major questions asked of him were concerning his goals for the course, what he felt the students gained from the course, and how this course was structured differently from other science courses offered at the University of Tennessee.

Description of the Participants

As stated, all participants completed a year-long internship in teaching as part of the master's and certification requirements program at the University of Tennessee and were currently teaching in public high schools in Tennessee. Two of the research participants completed the "Do It" course in 1997, five in 1998, and one in 1999. Six participants were teaching biology as well as other courses, one was teaching physical science and chemistry, and one was teaching physical science and a basic introductory science course. Six participants were females and two were males. All were certified to teach biology.

Ethical Issues

The participants of the "Do It" course had signed informed consent releases when they began the course. Students were assured that their identities would be kept private with pseudonyms used in research reports.

Data Collection and Analysis

The two processes of data collection and data analysis merge; therefore, they will be discussed together. In qualitative research, data is analyzed while it is being collected. Glaser and Strauss (1968) describe a method of comparative analysis in which questions and objectives are refined at various points during data collection. After several participants have been interviewed and the results analyzed the researcher can make comparisons between participants. These comparisons can in turn be used to better direct further interviews and analysis. The discussion guide, interview process, and analytical methods will be discussed in this section.

Discussion Guide

Purpose of a Guide

The discussion guide is a list of questions that are designed to allow the researcher to gather information regarding the overall research question(s) (Maxwell, 1996; Taylor & Bogdan, 1984). According to Patton (1990), the questions in an interview guide provide a framework that can allow the interviewer to explore, probe, and illuminate specific topics. Using the guide as a focus, the interviewer is free to develop questions that emerge spontaneously from the discussion with the participant. The sequence of questions may vary depending on the respondent's answers.

How the Initial Guide was Structured.

Originally, the discussion guide was based on suggestions/requests from Dr. Melear. Melear wanted to know how the course affected the participants and if the course had influenced and/or prepared them for teaching for inquiry, if at all. She wanted to know how they compared the course to other courses they had as students at the university. This guide was used for the seven interviews that were completed in the Fall semester of 2000.

Revisions to the Guide.

The original discussion guide was revised as the first author became more familiar with interviewing (See Appendix). Most of the questions remained the same; however, questions were rearranged and several new ones were added. One interview was conducted using this revised guide.

Suggestions from McCracken (1988) were used to revise the initial guide. The first questions of the interview guide should be structured to put the respondent at ease and to help establish rapport. These questions should be biographical and allow the participant to describe his/her life freely (See Appendix; questions 1-4). Following the biographical information there should be a list of questions that request an overview of particular matters of interest, called grand-tour questions (See Appendix; questions 5-9). The interviewer's responsibility is to listen carefully to the respondent's words and remember phrases and situations that can be probed for further information. The guide used in this study began with biographical questions, followed by several grand-tour questions with probes that asked respondents to describe the "Do It" course, and concluded with several questions that asked how they have applied the course to their teaching. McCracken strongly suggests that questions should be open-ended and allow the participants to respond freely using their own terms (See Appendix; question 1, 4, 6).

Interview Process

Each interview was conducted at a place and time that was convenient for the participant. Each participant was informed prior to the interview that the conversation would be audio-taped. The length of the interviews ranged from 25-40 minutes. Each interview was transcribed from the tape.

Allowing the participant to choose a time and place helped create a comfortable atmosphere because it gave the participant some control of the situation. The interview that was conducted with the eighth participant and the instructor of the course most accurately followed appropriate interview conditions because of author training.

Analysis

The process of analyzing the data for this research project included arranging the interview transcripts in a way that helped increase understanding of them and allowed for the presentation of findings to others. Bogdan and Biklen (1992) describe two approaches to data analysis: one in which data analysis is concurrent with collection and the other in which data analysis occurs after collection. They suggest that beginning researchers should complete some analysis during collection periods but that most analysis should be completed after data collection is complete. As a beginning researcher the first author followed their advice. The types of analysis that Suters completed during data collection included revising the interview guide to help develop rapport with the respondents and to improve it's quality as a means for providing answers to the research questions. She wrote memos, or short notes about what she learned from the interviews. Memos were also helpful in organizing her thoughts concerning the literature on the research topic and about qualitative research in general.

Analysis after Data Collection

Suters followed a method of analysis suggested by Bodgan and Biklen (1992). They consider analysis to be a process of data reduction. The first step was to number the lines of each interview transcript sequentially and to read over them several times. A preliminary list of coding categories was developed from the transcripts by looking for regularities and patterns. Preliminary codes were limited and refined to a final list of codes. The final codes were assigned numbers and matched to particular pieces of data within transcripts. Suters used a different colored pencil for each category code to mark the transcripts. Once the transcripts were marked with different categories, she copied and pasted sections of the transcripts within *Microsoft Word '97* to make lists of all instances found for each individual coding category.

Suters chose to develop coding categories based on what Bodgan and Biklen (1992) call preassigned codes. These are codes that are used when a researcher is asked to explore particular aspects of the participant's views. The following list of codes were used to help sort the data:

Teacher's view(s) of:

1. self as teacher
2. his/her students as learners
3. learning by inquiry
4. how they were changed by the "Do It" course
5. teaching with inquiry
6. nature of science and how it was changed by the "Do It" course
7. other courses compared to the "Do It" course
8. changes that should be made in college courses

Patterns were examined between participants for each coding category. These patterns were used to combine the coding categories based upon similarities between them and to form assertions (See Table 1 for assertions). Code one and two were combined to form assertion one. Code five formed assertion two. Code three and parts of code four and eight formed assertion three. Code six, seven, and parts of four and eight were used to form assertion four. These assertions are described within the "Results" section of this paper. Instances that did not conform to the theory are reported. Several quotes from the interview with Hickok were used to support the assertions that were revealed by the "Do It" participant interviews.

Validity

Maxwell (1996) proposes several questions that address the validity of research design.

> How might you be wrong? What are the plausible alternative explanations and validity threats to the potential conclusions of your study, and how will you deal with these? How do the data that you have, or that you could collect, support or challenge your ideas about what's going on? Why should we believe your results? (pp. 4-5)

These questions are addressed in this section of the paper. The issue of generalizability is also addressed.

Table 1

Assertions with Representative Examples

1. These teachers expressed student-centered views of their teaching; however, several presented dilemmas with teaching by inquiry.	I don't want to say non-traditional, but I kind of bring everything to life. Not that we necessarily do tons and tons of inquiry, but we do hands-on or involvement things. You know we get up and dance out a process or we get up and play "Red Rover" to illustrate osmosis or something like that. So, we involve ourselves somehow directly in the process. . . . . These kids that I'm teaching, my kids would not tolerate being frustrated that long. They would quit and you couldn't get back into it. So, it might take a little more leading and a little more prompting to really keep the motivation up. **(#3)*** Um, I believe that they learn best when they are engaged in the learning themselves with me just being the facilitator rather than just the lecturer. They always seem to do better if they can just discover things on their own. And um, they will always retain that information better than if I just get up there and give it to them on the overhead projector or something like that. So um, I think the students learn best when they discover things on their own and they're actually doing hands-on things on their own. (#8)
2. These teachers had varied comfort levels concerning their abilities to teach by inquiry.	Now when I teach, one thing that I do is I bring in aquarium tubing and bb's and let kids build a roller coaster. And I say, OK figure it out how to make the bb stop at the end of the tubing. . . .You know, you can't help them and they just have to kind of learn it on their own and they get frustrated. You know when they finally figure it out it's neat to watch. (#1) I guess the hardest part is knowing what kind of activities, hands-on, can I use to get them to learn this topic. If I have a curriculum that I have to use and I have to cover so much in a semester, how do I know at what point can I do inquiry? (#2)

3. These teachers had never used complete inquiry before in connection with a science course; they initially found inquiry frustrating, but they learned techniques, concepts, and the processes of science.	I understood the point about a month after I took the course. I learned about… they said doing science actually learning by doing, actually learning by thinking. I suppose one thing I got from the course was learning how to think scientifically. (#5) And I also think it taught me actually how to design an experiment. Before that I had taken science classes and everything and lab classes like genetics lab and stuff like that. We had to follow a cookbook recipe and I was never actually allowed to design my own experiment. So I think it gave me a chance to see what a scientist actually does. How, you know, to design an experiment. (#6)
4. These teachers' views of the nature of science were changed by the "Do It" course by helping them learn how to design and conduct an experiment and by learning that mistakes are a natural part of science.	But I learned more about how to set up a controlled experiment and in all four years of college, I didn't ever do that. I didn't even do it in high school. That's one thing that I'm making sure to teach my students, what's a variable, what's a constant, what's an independent variable, what's a dependent variable, what's a hypothesis, when do you state the problem, what's the steps, when do you publish data, when do you analyze your results? (#2) It was probably the best class I took as an undergrad. **What made it different from other courses that made it better?** Oh, so many things, because it was unlike any course I'd ever taken. Even you know, you take your science classes with labs that every lab you go into there's at least 30 people in the lab. You're just kind of following directions, reading step by step what you're doing. And this was neat because we had 2 professors in there with just 7 of us. So it was my first opportunity to have kind of a one-on-one relationship with one of my teachers whom, I have had him before and that made it more interesting because I knew him you know as a lecturer, and then to see him in that setting was really neat for me. And like I said the whole scientific process…like you learn the scientific method but you don't ever really use it. So this was actually an opportunity…you know we were creating our own hypotheses and we were running the experiments and then going back and analyzing our results and then changing our hypotheses and then changing our experiments and that kind of thing. So it was actually an opportunity to do science. (#8)

***(# __)** – Corresponds to interview participant

Discrepant data has been included as part of the results. Verbatim transcripts were used to insure that there was data to support assertions about the participants' views in their own words. These are called emic descriptions or rich data (Maxwell, 1996). It is possible to avoid misinterpreting the participants' constructed meanings by using the participants' exact wording.

Maxwell (1996) states that "what an informant says is always a function of the interviewer in an interview situation" (p. 91). Therefore, in order to collect information that truly reflected the understandings of the participants, leading questions were avoided. The discussion guide was helpful in doing this because open-ended questions were used.

The first author explored how she felt about this research topic and her personal experiences related to the topic of science education and scientific inquiry. In reviewing her "cultural categories" she felt she would be better prepared as a teacher as well as more scientifically literate if she had participated in a research experience as part of her teacher education program at the University of Tennessee. This bias could be considered a potential threat to the results; however, Suters' personal opinion was not imposed on the participants' data. The use of the verbatim transcriptions and the discrepant evidence were ways to accurately represent the feelings/opinions of each participant.

Triangulation was attempted to help validate the data. Eight participants were interviewed and therefore eight different perspectives were available. The interview with Dr. Hickok also provided another perspective of the students and the course.

Generalizablity

The results of this study can have external generalizability or have "generalizability beyond (that) setting or group" (Maxwell, 1996, p. 97). Maxwell states that "the generalizability of qualitative studies usually is based, not on explicit sampling of some defined population to which the results can be extended but on the development of a theory that can be extended to other cases" (p. 97). Therefore, the assertions that are drawn from this proposed study could be used to strengthen science teacher education programs in general.

Results

The findings of this study have been organized around the research questions. Information from the interview with the "Do It" course instructor, Dr. Leslie G. Hickok, has been used to support the assertions in some cases. The "Do It" course helped some of the students understand how to teach by inquiry; however, due to time constraints, the lack of experience on the part of the student with inquiry and the lack of the teacher's experience teaching, most of these teachers are teaching only small, guided inquiry activities on a regular basis. Based upon participants' responses, their views on some elements of the nature of science seemed to be influenced positively by the "Do It" course. All participants expressed the view that they had never had a course like the "Do It" course before. They felt that it gave them experience with the real processes of science. Four assertions have been identified from the analysis of the collected data. The assertions are described with representative examples in Table 1.

Results concerning question one: Relationship between course and participants' teaching with inquiry

Our first research question was aimed towards discovering if the course helped the participants understand how to teach by inquiry. The first two assertions in Table 1 relate to this question. *Assertion one* is these teachers expressed student-centered views of their teaching; however, several presented dilemmas with teaching by inquiry. They had a strong desire to provide authentic, meaningful activities for their students. They used words such as hands-on, enthusiastic, entertaining, and meaningful to describe their teaching.

Assertion two is these teachers had varied comfort levels concerning their abilities to teach by inquiry. Although the teachers felt that being student-centered was the most appropriate way to teach there were several problems mentioned concerning providing inquiry-based experiences for their students. These problems are listed in Table 2 and some specific examples follow. Participant two was teaching chemistry and physical science (rather than her major, biology) and did not feel comfortable teaching with inquiry. She stated this as follows:

> So, I don't know when and how I can incorporate the inquiry based on the topics that I have to cover. With me not being completely familiar with the material, I feel like I'm going to be discovering just as much as they are.

Table 2
Summary of constraints to teaching inquiry-based science

1. Teacher not familiar with content
2. Frustration on part of student - New way to learn and requires constant motivation
3. Frustration on part of teacher - New way to teach
4. Time consuming - Hard to meet curriculum requirements
5. Hard to find other teachers who are using the inquiry-based style
6. Student safety
7. Being a new teacher

Participant three felt that her students became frustrated and needed constant motivation to complete inquiry-based lessons. Participant four found it difficult to teach what she called "full-complete inquiry" due to trying to fulfill curriculum requirements and therefore felt a time constraint. Participant seven mentioned several problems he had with trying to teach using inquiry. He stated:

> Now, I'm still trying to look at people in the real world, real teachers, and compare to them. Not many of them are teaching by inquiry-style . . . I don't use it a lot right now, the inquiry style, because I don't think I really know what I'm doing . . . and just today I had terrible results with that because they became unsafe. In you know, a biology situation, chemistry, and science, I can't have kids working if they're unsafe . . . I think it's a good strategy, it's just that the kids haven't learned that way for 10, 5, however many years they go to school, and I'm a new teacher. So, it's a double whammy.

Frustration seemed to be a common theme concerning inquiry-based learning and teaching. As students in the "Do It" course, these teachers were all frustrated with this new method of learning. They stated that they had never had a course like this one before. As mentioned above, some of these teachers had difficulties teaching their own students in this way. Several stated that their own students were frustrated with inquiry-based teaching. The instructor of the "Do It" course stated:

> How hard it is for me to teach that way I guess surprised me more than anything else. The uh, especially the first two years, maybe it's not so difficult now, the first two years just keeping my mouth shut was so difficult.

Despite the constraints and frustrations mentioned by these teachers the majority of those interviewed are attempting to provide some guided inquiry experiences for their students. Three of the participants stated that they felt comfortable teaching inquiry despite these constraints. Participant one stated:

> At first no, I thought I could never do this. But, you know, after we finished the course, yah, I think it was pretty easy.

Participant five was teaching a course called Introductory Physical Science (IPS) and stated:

> One of the very first activities of the year in my IPS class, which actually is an inquiry-based class, was to give them a box full of stuff and have them come up with science experiments that they could perform, using the box of stuff. I didn't give them very much help at all. I just let them do it and when they did it and wrote it up we talked about it. I offered suggestions on how to make it better. I think that's kind of the same deal as the "Do It" class when they gave me the powder and told me to learn about it.

Participant eight had some reservations about teaching with inquiry but appears to have resolved them. She stated:

> Even after having had the class I was skeptical as to can these kids actually do this. If you give them stuff, can they really make it work and create something um, and do a lab experiment, and I was just not sure. That's what I did my action research project on in my master's program. It was just amazing to see the difference in the class that was doing the inquiry lab experiments versus the class that was doing the cookbook . . . and just retention was just the main thing, because those doing the inquiry remembered um, what the point of the lab was whereas the other kids, it just kind of went in one ear and out the other.

Results concerning research question two and three: Comparison of the "Do It" course to other courses as preparation for teaching science and for understanding the nature of science

The remaining two questions can be best answered in combination. Assertions three and four of Table 1 are restated here to illustrate. *Assertion three* is these teachers had never used complete inquiry before in connection with a science course; they initially found inquiry frustrating, but they learned techniques, concepts, and the processes of science. *Assertion four* is these teachers' views of the nature of science were changed by the "Do It" course by helping them learn how to design and conduct an experiment and by learning that mistakes are a natural part of science. The examples listed in Table 1 describe the overall view that this course was completely different from any other that these teachers had taken before. A statement by participant one provides an additional view:

> Ok you may have this hypothesis that doesn't work out. But maybe you didn't learn what you thought you would learn but you learned something else by it and how frustrating it can be to mess up. And it's not always, OK here's our idea and we're going to go to the lab and do some experiments and they're going to turn out exactly like we wanted. Because, it's not going to most of the time and you have to say, OK, figure out what you did wrong . . . Sometimes you learn a lot more from yo mistakes than you do from like what you initially think you are going to learn.

Hickok, the instructor of the "Do It" course, observed the frustrations the students had with the course. He feels that the way science teachers have traditionally been trained gives them a lot of content knowledge and allows them to teach out of a textbook well. However, in terms of producing the inquiry-kind of teaching there is some deficiency. Furthermore, he stated in an interview with the first author, that even though the students in his course have had biology training they are not prepared for the course. He had taught several of these students before in non-inquiry-based format science courses and felt that they were above average students. Even these students, who he considered to be very bright, who also had high grade-point averages struggled with the design of the course. He stated:

> I was really surprised at their sometimes anger, too. They uh, especially the good book learners, you know the pre-med types, they just wanted to say, cut this baloney out and just tell me what I need to know and I'll know it. . . . So that surprised me, the anger that they had. And in a way, I guess it doesn't because you know, they do, they're successful in the educational system the way it is. And they get angry when you try to do something different with them.

Dr. Hickok feels that the students benefit from the course in two ways. First, they gain an awareness that they have not previously been equipped to do pure experimental science. Second, when they go through the experience of this inquiry-based course, it gives them the confidence to work with some of the equipment and methods of science that they have not had experience with before. In his interview with Suters he stated:

> I think what I'm finding out is that the course provides an opportunity to sort of maybe see what things can be like but in order to really get there it, you know, requires more just digging at it yourself. So by no means do I think we are putting out a finished product with this course even though that was the initial intent.

A statement made by participant eight seems to correlate with Dr. Hickok's statement. Concerning the course, she said:

> I just feel that it really changed my whole perspective on how to teach because growing up and then going through undergrad you have labs spit at you and then you just regurgitate the information back and that's it. And um, it really made me look, I guess it was unique because I was actually the student and I got to see and go through the emotions and feel what it was like you know, to be a part of that and you know actually having a total inquiry-based course. And it just really changed me as far as I would have never taught the way I teach now if I hadn't had that.

This participant also felt that fellow students that she met as an intern who hadn't had the course were missing out. If inquiry was discussed or attempted in their science methods courses those students who had not completed the "Do It" course seemed to not understand fully what was being discussed.

Discussion

During a teacher's first year many of the responsibilities of teaching can be overwhelming and can prevent a science teacher from using student-centered styles advocated by most pre-service science teacher education programs. In addition, teachers appear to be imprinted by the end of the first year of teaching. They continue to teach in the way that they taught in their first year. However, one way to help new science teachers institute student-centered, inquiry practices in their classroom is to ask them to reflect upon their pre-service preparation program (Adams & Krockover, 1999). This reflection can help them remember what they learned and practiced as part of teacher preparation programs and in some cases help them change their teaching practices. Providing support and transition activities for these new teachers is something for which universities should be prepared.

Duggan-Haas (1998a) stated that research experiences for science education students can often change the world view of those who complete them or "trigger an epiphany about the nature of science" (p. 6). Changes in a person's world-view can be understood best from the participant's own descriptive words. The teachers in this study expressed the desire to teach using student-centered styles which include using inquiry-based methods. Possibly these interviews had the added benefit of helping the new teachers reflect upon their educational preparation in these critical first few years of their teaching, where reflection can help them change their teaching practices if necessary. Patton (1990) states that although the goal of interviews is to gather information, "the process of being taken through a directed, reflective process affects the persons being interviewed and leaves them knowing things about themselves they didn't know…before the interview…(this) can be change-inducing" (pp. 353-354).

The results of this study with these teachers implies that involvement in an inquiry-based course is just a beginning step in the process of preparing teachers to teach using inquiry. The course has helped these teachers become more scientifically literate by involving them in the actual processes used by scientists. However, the ability to teach using these methods has been shown to be challenging. When these teachers do not have others in their own school who teach using inquiry, or people they can talk to as they could in their pre-service preparation program, their ability to develop skills teaching with inquiry is hampered.

Recommendations

The implications for new science teachers as well as those that are experienced are that they need to work together to try to break the traditional cycle of teaching science through predominately a lecture-based classroom towards an inquiry-based classroom. There should be a consistent trend within schools in which most science teachers teach with inquiry. The teachers in this study experienced the same feelings of frustration in the "Do It" course that they are seeing exhibited by their students when they teach using inquiry. These teachers also expressed that after becoming accustomed to asking their own questions and seeking the answers to them, they enjoyed the class. When students are given many opportunities to learn with inquiry, as the research participants did, they may learn to enjoy the method as well.

Other suggestions to encourage classroom science teachers to implement inquiry-based activities include participation in professional development activities. Teachers who have used the method successfully who share their ideas through workshops or publications can influence other teachers to try the method. Science teachers should also be encouraged to continue their own education. There are many internet-based courses as well as courses offered at local universities which teachers can participate in to strengthen and/or update their skills. As knowledge of the successes and failures of inquiry-based methods is made public, science teachers can develop plans to implement activities accordingly.

Conclusions

In summary, this study has used qualitative research methods to explore the views held by its participants of the longitudinal effects of an inquiry-based research experience. By placing pre-service science teachers in a situation in which they are required to design their own research experiments, they are given an opportunity to learn in a way that promotes scientific literacy. One of the purposes of this study was to see if these teachers feel more comfortable with implementing inquiry-based learning experiences within their own classrooms. Since the impact of pre-service education programs may not be evident until teachers have been teaching two or three years, or more this type of longitudinal research can be very helpful in determining the effectiveness of teacher education programs. It is possible that results of this intervention may not be detectable until four years of teaching.

The results of this study can contribute to the quality of the science teacher education program at the University of Tennessee. Theory that is developed from the results, for example the assertions that have been made about these teachers, can be used to help develop programs like this at the University of Tennessee as well as other universities. These teachers appear to be very enthusiastic about the course and about what it has done for them personally and professionally, even though more have demonstrated that the objective of how to teach by inquiry has not been attained yet.

As a nation, it has been shown that science skills and knowledge are lacking. We have a great deal of improvements to make in our educational system. A course, such as the "Do It" course, is just the beginning. Ideally, students need to start learning science by inquiry in elementary school. Science education is sometimes omitted or pushed aside in order to emphasize reading and writing. The emphasis on science learning by inquiry should be continued then throughout the child's education. Questions that arise from this study include:

1. What are some ways to help new science teachers overcome the obstacles of beginning teaching and use inquiry-based teaching as part of their repertoire?

2. What can universities do to provide support and transition activities for new science educators?
3. Would providing a course such as the "Do It" course to elementary educators help improve elementary science education?

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Appendix

Interview questions with probes for "Teaching Science-Just Do It" course

1. Tell me a little about yourself.	▪ What and where do you teach?
2. How would you describe yourself as a classroom teacher?	
3. How do you believe your students learn best?	
4. What is the meaning of the nature of science to you?	
5. When did you take the "Teaching Science? Just Do It" course	▪ At what point in your college career did you take the course? ▪ How long have you been teaching since you have taken the course?
6. Describe what the "Do It" course was like.	▪ What was your initial reaction to the course? ▪ Did your reactions to the course change over the time that you were taking it? How? Or how not? ▪ What were the expectations of the instructor? ▪ What did you do during the course? ▪ Does the title of the course have any meaning to you?
7. Had you experienced a course like this one before? Have you experienced a course like this one since then?	▪ Explain
8. Did the course prepare you in any way for teaching?	▪ Did the experiences you had with inquiry in the course help you understand how to teach by inquiry? How or how not? ▪ Did you learn any new concepts about how to learn science from this course? If so, what were they? (Possibly inquiry) Do you try to use them with your students?
9. While you were taking the course, did you feel that you could teach students in the way that the course was taught?	▪ How do you feel now?
10. How does this course compare to other	▪ Teacher methods courses or pure

courses you had as an undergraduate or graduate student in preparing you to teach?	science courses
11. After experiencing __ years of teaching, what changes would you suggest professors make in their courses to make their courses more meaningful and useful for you?	- Teacher methods courses or pure science courses
12. Did the "Just Do It" course help you understand science?	- Did you learn anything new to you? If so what? (Anything from equipment use to concepts) - Did you feel that the structure of the course helped you understand the nature of science?
13. Would you recommend the course be required of future biology teachers?	- If so, are there any changes you would recommend?

PROVIDING AN ASTRONOMICAL RESEARCH EXPERIENCE FOR IN-SERVICE AND PRE-SERVICE TEACHERS

John W. Wilson, Georgia State University
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Project History

The idea for this project began at the Southeastern Association for the Education of Teachers in Science (SAETS) meeting held 8-9 October 2000, at Auburn University. While attending a session on inquiry-based learning we heard papers by Hahn and Gilmer (2000) and Melear (2000). On the drive home we had a very stimulating conversation about how Dr. Melear's work could become a dissertation project for John Wilson, who was a second year Ph.D. student in science education at Georgia State University (GSU). During the next week Wilson contacted Dr. Melear for additional papers concerning her immersion project. While reading these papers he realized that he might be able to use a directed studies type course at GSU to attempt an immersion experience in astronomy with pre-service and in-service science teachers who were working on Master of Education Degrees.

Throughout the late fall of 2000 and the winter of 2001 we began to develop the idea of using ASTR 7910 as a vehicle for doing some research on immersion of teachers into the culture of science. Melear (2000) had discussed two methods for providing an immersion experience (Figure 1). The first way was to have pre-service teachers and in-service teachers actually work on scientific teams as integral parts of the team. This means helping to make scientific decisions for the team and thus to be fully engaged as a participant and not simply hanging around. Hahn and Gilmer (2000) had also been doing research with teachers working on scientific teams. Melear's second method was to have the pre-service and in-service teachers take a course that is taught by a scientist using unconventional pedagogy. This type of course would focus on the students posing their own questions and embarking on a scientific way of trying to answer their questions, similar to how a practicing scientist might do science. She was already doing the later method with Dr. Hickok (Hickok et al. 1998) for a Botany class at University of Tennessee, Knoxville (UTK).

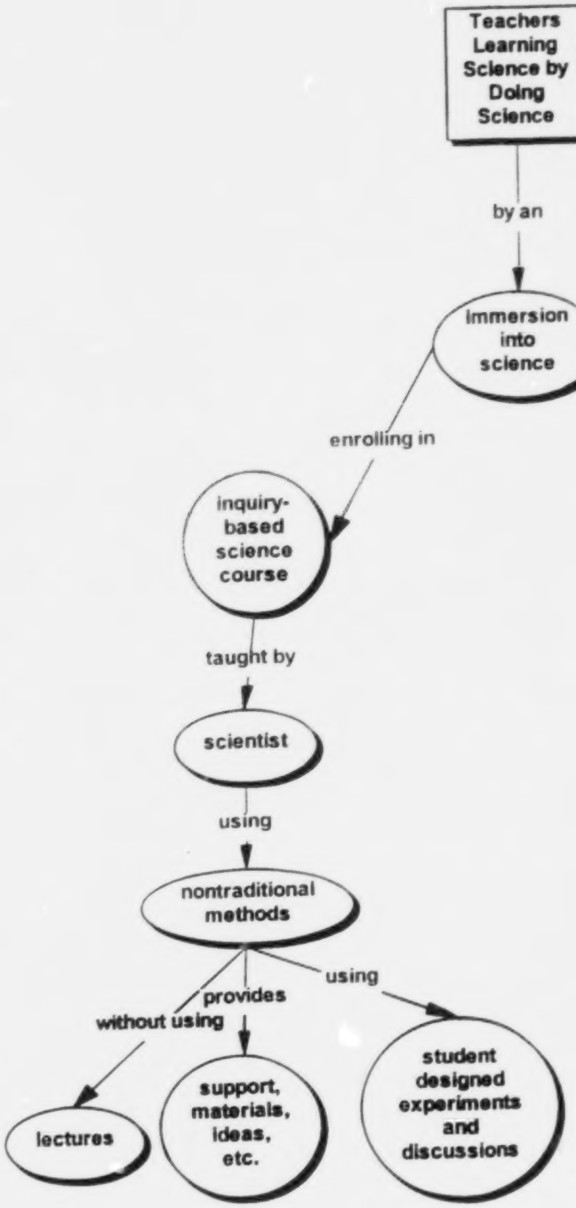
Teachers Learning Science by Doing Science
by an
immersion into science
enrolling in
participation in
inquiry-based science course
actual scientific research experience
taught by
working with
scientist
scientist
using
nontraditional methods
could be
could be as
without using
provides
using
individually
part of a team or project
lectures
support, materials, ideas, etc.
student designed experiments and discussions

Figure 1: A concept map showing two ways in which teachers may be able to experience the culture of science as described by Melear (2000).

In April 2001 we visited Dr. Melear and Dr. Hickok's Botany class in order to observe how they conducted this course and how their students felt about the class. This class was conducted in two separate parts. During the first half of the term all student groups studied C-Ferns using methods of scientific inquiry. During the second half each student group asked their own questions about some botany topic. Then they developed experiments in an attempt to answer their questions. It was near the end of the second half that we made our observations and interviewed each group. This experience was very informative and allowed us to more clearly envision how this type of course is conducted and how the students performed.

We learned several interesting things from our observations and interviews. As expected the students did not like this experience at the beginning of the semester. One student put it like this, "Well it was a lot of lip biting and fist clenching and AUGH" and "Yeah, it was a forced inquiry for the first few days until we got into – ok we are not going to be given any answers. We need to come up with this …" As the semester progressed the students' attitudes must have changed. Our observations showed that they all seemed to be having fun and were interested in doing their own personalized investigations. Many of their comments were positive and confident. As they reflected on the first half, they seemed to have grasped its importance and viewed it as a positive experience. The same student quoted above later said,

> You have to be very open-minded to other people's observations and methods for experiments and uhm… I mean it really helps, I would say, and student grasp the scientific method. You have to go through those individual steps.

Based on the above quotes, it appears that this student feels they have learned how to do science and how to conduct lab experiments. Learning how to do science is one of the things that science students can only learn by experience.

It readily became apparent to us that these students were genuinely engaged in the process of asking and seeking answers to questions such as, "What does this mean?" and "What would happen if?" They exemplified the vision of scientific inquiry described in the National Science Education Standards (NRC, 1996). It seemed to us that they had enhanced their abilities to perform scientific investigations and developed a deeper understanding of scientific inquiry. The learning environment we saw was consistent with both personal and contextual views of constructivism. The students recounted how they became more responsible for conducting their research and how they progressed from being students in a class to members of a functioning research team.

Creating an Astronomy Experience at GSU

Throughout the winter and spring of 2001 Wilson worked on creating a similar course in astronomy that would give teachers an authentic experience with astronomical research. Because he is an astronomer and had participated on research teams, he decided to combine the ideas shown in Figure 1. In the Summer 2001 semester he attempted to use ASTR 7910 to create a research team from pre-service and in-service teachers. The idea was that he would act as the project director and the students would be the research team. So, this class was an immersion experience similar to the UTK botany class, but it includes elements of being on an actual research team for the summer. These students were taking a class that attempted to use unconventional pedagogy to turn them into a research team.

Wilson has been in astronomy as an amateur and a professional for over 30 years. During that time he has seen, and experienced the excitement that astronomy arouses in people. When people view the Moon, or Jupiter, or Saturn through a telescope there is almost always some comment like, "Oh wow, you've gotta see this" or "It (usually referring to Saturn) looks like a little tiny picture." Other objects, such as nebulae and galaxies, tend not to elicit such strong reactions from people. However, they still enjoy viewing them and talking about what they have seen in the telescopes. In general he has seen that people are excited by simply look through a large telescope at the night sky. There seems to be some mystique associated with studying the Cosmos that naturally attracts people to astronomy.

Astronomy is a science that has strong public appeal. During the last twenty years, the Public Broadcasting System have televised many astronomical related programs such as *Cosmos*, *Steven Hawking's Universe*, *The Astronomers*, and numerous episodes of NOVA. Astronomical events, such as meteor showers and eclipses, are frequently mentioned on local news broadcast and in newspapers. Public programs at observatories and planetariums attract hundreds of people. GSU's observatory, Hard

Labor Creek Observatory (HLCO), typically has between 100 and 200 people per night at its monthly open house nights. Introductory astronomy classes at GSU are nearly always full with current enrollments near 650 students each semester. Wilson felt he could capitalize on the popularity of astronomy to encourage a few pre-service and in-service teachers to enroll in an astronomical research course in which they would use large telescopes to collect their own data.

We wanted the research project for this class to be an authentic experience in observational astronomy that would cause the students to grow in knowledge and be a positive experience they would not forget easily, similar to Wong et al., (2001) description of a Deweyan experience. Two elements that we wanted to include where having the students make their own astronomical observations, and for these observations to make at least a tiny authentic contribution to the astronomical database. In other words we wanted them to do astronomical research that could be used by research astronomers. In addition we hoped this experience would generate within some of the teachers the desire to continue learning astronomy. Maybe the ultimate outcome would be if these teachers included some basic amateur level astronomy as part of any science classes they teach.

Selection of a research topic that fit the above goals was difficult to choose. Wilson wanted to use his own research experience, but it had to be at a level that inexperienced observers could accomplish in a summer semester. In addition he wanted the initial response to the project and observing to have that "wow" experience described above. Some possible topics we discussed were photometric observations of variable stars, photometric observations of Active Galactic Nuclei, sunspot counting, and binary star observing. Photometric observations are not difficult, but the data reductions are tedious and difficult to learn. It is not until all of these reductions are complete that you even know if your data is of good quality. So, the "wow" effect would be delayed or never occur at all. In addition photometry requires nearly perfect sky conditions, which are rare during a typical Georgia summer. Wilson decided that data reduction difficulties and typical summer climatic conditions would prevent obtaining useful photometric results in a short summer term. Another possibility was counting sunspots for the American Association of Variable Star Observers. This was appealing because it could be done during actual class time hours. However, it did not lend itself well to going out under the night sky for a more total immersion into an astronomical experience. Observing visual binary stars seemed to have all the right characteristics, it could probably be done in the summer term, it provided a nighttime experience with the real sky using large telescopes, and the data reductions are straightforward. Because binary stars are in fact double stars, you instantly know if you have seen a binary star or not, which provided the "Wow, I found it" experience we were looking for. So, measuring the position angles and separations of visual binary stars was selected as the astronomical research topic for this course.

The Universe is so large that professional astronomers cannot observe every star every night. Astronomy is still one of the few sciences in which amateurs can still make a significant contribution. Tanguay (1999) discusses the need for amateur astronomers to assist professional astronomers with monitoring the hundreds-of-thousands of visual binary stars. The long term monitoring of the separations and position angles of widely separated binary stars (>5 arcsec) has been virtually neglected by professional astronomers. Brian Mason, an astronomer at the United States Naval Observatory (USNO) in Washington D.C. has made a list of nearly ten thousand neglected visual binary stars. Many of these binaries have not been observed for over twenty years, including some that have not been observed for over one hundred years. This list also includes binaries that have only a single observation and need a confirming observation. Resent European Space Agency missions have generated two new astrometric databases, The Hipparcos and Tycho Catalogues (ESA, 1997) also contain first time observations of previously unknown binary stars that need ground-based confirmations. Therefore, Wilson decided that measuring the position angles and separations of some neglected binary stars was a worthy project that needed to be done. Any data collected by this research team could possibly be submitted to the USNO's astrometry group.

Choosing to work on a project for the Naval Observatory provided an end target at which the students could aim, or direct their efforts. John Dewey (1916) described three characteristics that good aims should have: (1) Aims should be based on things that are already going on, (2) Aims should be a tentative outline of what should occur and thus provide guidance and direction for the students. That allows the students and the teacher to see the progress made while doing the project, and (3) Aims provide a way to view the end, or conclusion of some process. The choice of observing visual binary stars listed as neglected in the Washington Double Star Catalog (WDS) connected this research to a project that was already in place and needed doing. Thus the students would be immersed into the history and culture from which this research has come. Because these stars had not been observed recently the aim was in fact tentative. Wilson knew what the data should look like. However, no one knew what the new position angles and separations would be. In addition it was possible that these stars have been neglected for so long that they cannot be clearly identified in the sky. Thus, the possibility existed that the students would obtain a null result because it might not be possible to conclusively identify the binary in the sky. This project was to be brought to a logical conclusion by having the students present poster papers to the astronomy faculty and graduate students at GSU and possibly submitting the data to USNO for inclusion in the WDS. Doing simple visual binary star research provided the students in this course with a good target at which to aim their research efforts.

Development of the ASTR 7910 and its Assessment Strategies

During the summer 2001 semester at GSU Wilson conducted a pilot study on this project. So far the results are encouraging. Twelve teachers enrolled in the course. From their e-mails and telephone conversations they all seemed excited about the prospect of doing real astronomy at an observatory. The real attraction seemed to be presenting their data to astronomers at the USNO.

During the first week of the class one student said:

> That was the reason I took the course, because we were going to do real research for the Naval Academy (she meant Naval Observatory) and not just do ordinary labs.

In this Binary Stars class Wilson used a variety of assessment tools. Each student constructed a concept map on binary stars each week. These revealed their knowledge about binary stars and astronomy in general as it related to their research. Each student also kept two journals. One of these was a scientific journal about the science they were doing on binary stars, and the other was reflective journal on their feelings about their progress and learning. These two journals showed how they approached their research and how they felt about the process. Finally each group produced a poster paper that was presented to the GSU astronomy faculty and graduate students at an afternoon seminar on 30 July 2001. These four student products were used to assess the content learned and for internal consistency of the data. Throughout this course Wilson also made his own observations of the students. Audiotapes of some class discussions and observation sessions were made to capture the excitement and boredom that occurred during the astronomical experience. Photographs of the students as they made observations were also taken. These data sources are being used to triangulate the data for validity and reliability.

Doing It

Because Wilson wanted to teach this class using nontraditional techniques he did not use a specific textbook. The students could use any textbooks, magazines, or other materials as references sources. A course WEB site was constructed by Wilson (2001) that the students could use throughout this course. This site included content specific to binary stars and how to observe them. As part of this site both amateur and professional resources were included. In addition to WEB based resources, current issues of popular magazines such as *Sky & Telescope* and *Astronomy* were required course materials. In addition, copies of articles from past issues of these magazines, which described double star observing at an amateur/professional level were provided to the students. It was felt that using these resources, instead of formal textbooks, would provide the students with a wider range of material at an appropriate level from which to learn about binary stars and astronomy in general.

The first couple of classes were dedicated to assessing the students' prior knowledge and having in-class discussions about stars in general, and binary stars specifically. On the first day of class each student drew concept maps about binary stars. After this the remainder of class was spent discussing what stars are and what binary stars are. At the end of class the students were shown the course WEB site and told to explore it before the next class. The second class was spent using the course WEB site to answer questions the students had about it specifically, and about binary stars in general. This class was mainly student driven not instructor oriented. Dr. Melear had suggested that we should get the students outside with a real telescope as soon as possible. So at the end of this class the students were given

Tanguay's (1999) article and a lab exercise, Observing Double Stars, written by Dawson (2001). The lab was to be completed in small groups using amateur telescopes at HLCO on the first clear night available. This lab became the first in a series of milestones to be completed as the semester progressed, similar to those discussed by Polman (2000). These milestones provided some structure for the students so they would not postpone work until later, when it needed to be done now.

The students divided themselves into three small groups with four members per group. On the first couple of nights at the observatory each group used simple amateur telescopes to observe three different double stars, Mizar & Alcor, Alberio, and ε Lyrae. These three objects were selected because each one had a discovery, or surprise, to be found by the students. Minimal directions on how to aim the telescope were given, and then they were simply told to find these three binaries, starting with Mizar and Alcor. One of the astronomy graduate students was there and helped the students as needed, but he did not point the telescope for them. All three binaries were observed and the discoveries waiting to be found were surprising and motivating to the students. Without being prompted to do so, the students decided to look at Mars and some other astronomical sights after they had observed the binary stars.

During the next week's class period each group selected a binary star to observe. In addition the class discussed the HLCO observations they had made and what they had seen and learned about binary stars. This discussion included how close the stars were to each other when viewed with a telescope (angular separation), the orientation of the two stars relative to north (position angle), the colors for each star within the system, and the student's discovery that some binary stars are actually multiple stars with more than two stellar components. The discussion was then directed to the types of measurements that the students would make during the remainder of the summer. Basically each group was expected to determine the position angle and separation of one binary star system by the end of the summer term. As project director, Wilson told them to select stars from the list of neglected binaries in the Washington Double Star Catalog (WDS). They were told to select two, neglected double stars from the equatorial list. Because the director was not sure about the limiting separation that could be photographed, he also constrained them to stars whose separations were larger than 10 arc seconds. It was felt they still had plenty of stars from which select because the WDS currently has 2331 stars in the neglected list of equatorial double stars. The students were not given any further directions at this time. They came to the instructor only when they experienced a problem and to get approval of their choices. Not every choice was approved because some had selected stars too close together or stars that could not be observed from Georgia during the summer. After each group had selected their binary stars Wilson had them write a simple observing proposal requesting time and instrumentation at HLCO with which to make their observations. This observing proposal was one of the early milestones to be turned in. After their proposals had been reviewed they were granted time at HLCO to take images of their double stars.

During the next phase the students made their own binary star observations at HLCO using a 16-inch Bollar and Chivens telescope equipped with an Apogee AP-7 CCD camera. It was expected that each group would take several images of their binary star over three nights so they could use these images to take a grand seasonal mean of their data. However, because of weather conditions and time constraints the students and Wilson decided that the 4 or 5 images each group obtained on a single night for each star would be enough. We were also running short of time, so Wilson took images of six calibration binaries himself with the assistance of an undergraduate astronomy student. These calibration images were given to the class as a whole. Each individual group then contributed some of their members to work on calibrations and provide the results to all the groups. They got excellent results and even confirmed the telescope and camera image scale of 0.624 arc seconds per pixel that had previously been obtained independently by an astronomy graduate student during the spring of 2001. This confirmation gave them a great deal of confidence in their ability to work with these observations. Every group completed their data reductions successfully and actually determined a new separation and position angle for their selected binary star. In one case this was the first new data since the year 1906.

About half way through the summer Wilson suggested that the students look for archival data on their binary stars. As a starting point he had them read Sincell's (2001) article *Cybertrackers*. He describes how amateur astronomers and some high school students were using astronomical data collected off the Internet to do science. What Wilson wanted was for his astronomy students to look and see if they could locate images of their binary star in an archival image database. It seemed to him that this might be a way of obtaining additional data points. Therefore, the students could possibly report overlooked archival data as well as their own HLCO data. So instead of simply adding one new data point to their neglected double star they might be able to add two or three data points. In this way they would up-date the astronomical database to 2001 and fill in some previously missed data. Because of a time constraint, the three teams all agreed to use a single archival source, the Digitized Sky Survey, so that they could do a common calibration for this data. Two of the groups were successful with this archival data search. One group got confused and had to contact the Space Telescope Science Institute (STScI.) As it turned out STScI found that they had multiple images listed and that it was possible to obtain different images using the same exact request format. So the students helped STScI learn about a cross-reference problem between multiple image sources. This search of archival data did in fact yield more of a scientific contribution than first expected.

The final application, and milestone, was for the students to present their binary star data to an authentic audience of astronomers. During the last week of the summer term all three teams worked on scientific poster papers. These were patterned after poster papers that astronomers give at professional meetings such as the American Astronomical Society's annual meetings. On 30 July 2001 the astronomy faculty and graduate students at GSU hosted an afternoon tea at which the students presented their posters. These presentations were well done and given in a manner acceptable to the astronomers. After the presentations several of the faculty told us that they thought these students had done an excellent job considering that they knew very little astronomy at the beginning of the summer.

Conclusions and Future Plans

We think that this is an excellent way to use a directed studies type of course. These students were being directed and directing themselves throughout the semester. They were excited about being on an astronomical research team that was attempting to do authentic research. At the end of the summer the three teams were clearly operating together to accomplish a mutual goal. They no longer thought of themselves as individuals, or as separate groups, but as members of a larger team. While each group had specific goals, they learned to help each other by doing common calibrations that all the groups could use, similar to the way scientist share data. We think every student learned that research science is different from the science presented in textbooks and traditional labs. It is hoped that these students will use this experience to help them teach their own students how scientists actually do science.

We found that a six or seven week summer term is not long enough for this experience. The students were pushed to work rather fast so that they could obtain results. Just as they were becoming a team of researchers the semester suddenly ended. A way needs to be found to extend the length of time they have to work on the project. Then they may be able observe each binary star over several nights so they could improve the error bars on their data. It might even be possible to add a few more program stars to the observing list without feeling short of time. All of the students enjoyed the observing portion and seemed to do data reductions willingly. We believe the students did have a Deweyan experience in astronomy because they grew and had an experience they will never forget. Wong el al. (2001) says that Deweyan experiences should come to a natural conclusion and not simply end abruptly. At the 2001 annual meeting of the Southeastern Association for the Education of Teachers in Science three of these students in this class presented a paper (Davis, O'Brien, & Philpot, 2001) about their experiences in this course. Therefore, these three students brought the summer's research experience to an even more natural conclusion. On 19 November 2001, Brian Mason, from USNO, visited with me and saw the poster papers these students produced at the end of the summer. He has agreed that the data collected by these students at HLCO in 2001 should be included in his next up date of the WDS. He further agreed to work more closely with the students in future classes. So we can now say that these students have made an authentic contribution to the astronomical database, and have experienced the culture of science by doing astronomical research.

This class will be offered again during the Summer 2002 semester at GSU. So that the students can get a little more time to do some preliminary amateur astronomy the course may have an early observing session during the Maymester. This might take the form of a cookout at the observatory for the students and their families. After dinner they could identify constellations and complete the binary star observing lab. This would allow the students to get into binary star research a little sooner than they did in 2001. Another change that will be made is to have the students select their research program stars sooner and to make an immediate contact with astronomers at USNO to request previous observations of the stars they have selected. This would give the students another astronomer to work with during the summer who is not part of the class, and it would connect the students with the history of observations for the stars they have chosen to observe. We think this will improve the students' connections to research astronomers and to the astronomical history and culture as it pertains to their stars.

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TECHNOLOGY TOOLS FOR SUPPORTING SCIENTIFIC INQUIRY: A PRESERVICE SCIENCE EDUCATION COURSE

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The notion of scientific inquiry is at the core of the view of science teaching and learning that US educational reform has sponsored (Minstrell & van Zee, 2000b; National Research Council, 1996, 2000). However, teachers do not have experiences learning this way (Putnam & Borko, 1997). Thus, there is an urgent need to address this issue in teacher preparation programs. The purpose of this paper is to describe and discuss the rationale for the development of an innovative, technology-rich, inquiry-based science course for prospective secondary science teachers taught at a large university in the northeastern United States. In "Technology Tools for Supporting Scientific Inquiry" (SCIED 410), prospective secondary science teachers have the opportunity to learn science through inquiry and reflect on these experiences to reconsider their roles as teachers in a science classroom.

In this paper, we begin with a discussion of the rationale that framed the design of SCIED 410. Then a description of the course is provided, establishing connections between each element/activity and the rationale previously described. We conclude the paper with a brief discussion of the significance of such a course for research in science education.

Science as Exploration versus Science as Argumentation

Despite the importance of scientific inquiry in the context of science education, like many fundamental ideas in education, 'scientific inquiry' has come to acquire multiple meanings and in this process is losing much of its significance; hence, the importance of making clear the meaning of scientific inquiry in the context of reform (Bybee, 2000). Mainly at the elementary level, science teachers too often equate "scientific inquiry" with "hands-on activities" used to motivate children to learn science (Abell, Anderson, & Chezem, 2000; Wheeler, 2000). At the secondary level, on the other hand, science has been portrayed as a collection of facts or "stable truths to be verified" (Alberts, 2000; Bybee, 2000). These understandings are limiting in the sense that they overlook the complexities of reform-oriented understandings of scientific inquiry that could be particularly valuable to the learner.

Two elements of scientific inquiry *for science learners* have been emphasized in the *National Science Education Standards* (National Research Council, 1996): abilities to do scientific inquiry and understandings about science and scientific inquiry Doing scientific inquiry involves engaging in scientifically oriented questions, giving priority to evidence in responding to questions, formulating explanations from evidence, connecting explanations to scientific knowledge and communicating and justifying explanations (National Research Council, 2000), p. 29). 'Doing science' at school through these activities represents a shift in the focus of teaching: that is, less emphasis on "science as exploration and experiment" (or hands-on activities), and increasing emphasis on "science as argument and explanation" (or minds-on activities) (Abell et al., 2000; Kuhn, 1993; National Research Council, 1996).

The notion that *learning science* also means learning *a way of thinking* about nature underlies the other major dimension of scientific inquiry for learners, that is, that they should develop understandings about scientific inquiry. In other words, scientific inquiry from the reform-oriented perspective implies that through school science, students should learn *how* to "engage in a dialogue with the material world" (Minstrell & van Zee, 2000a; Wheeler, 2000). Moreover, in order to understand how scientific knowledge is constructed, it is not enough to understand scientists' practices. Rather, it is fundamental that science is understood in a cultural and social context (Abd-El-Khalick & Lederman, 2000). Science educators have called this broader construct 'nature of science' (NOS). Unfortunately, these aspects of scientific inquiry, in particular, have been overlooked in school science (Bybee, 2000).

How do we achieve a more encompassing understanding of scientific inquiry (and NOS) in school science so science learners develop both understandings about and abilities to do scientific inquiry? Teachers would have to create opportunities in the classrooms for students not only to engage in inquiry-based investigations, but also to think about what is involved in doing scientific inquiry. To do so, teachers must know first what is meant by scientific inquiry (besides having robust understandings of subject matter and inquiry-oriented teaching strategies) (Bybee, 2000). Unfortunately, many prospective teachers have not learned science in this way and know little if anything about inquiry. How, then, can they realize the vision of reform in their classrooms? It is the responsibility of teacher educators to provide support to teachers in this area. SCIED 410 was a course conceived to address certain aspects of this task. In the following section, we will describe the rationale that guided its design.

Learning to Teach with Technology

In recent years, teacher development has been seen as teacher learning (Bell, 1998; Putnam & Borko, 1997, 2000). A major implication of such a perspective is that recommendations for teacher education must be informed by learning theory in the same manner that K-12 education is. At least three central ideas about learning have been identified as central to teacher education: (1) knowledge is situated in a physical and social context (Brown, Collins, & Duiguid, 1989), thus, knowledge about science teaching should be situated in an appropriate context (Putnam & Borko, 1997, 2000); (2) learning is seen as interpretation of experiences and the learner has an active role in that process, thus, teachers should be exposed to new experiences and should have the opportunity to reflect upon them, rethinking previous experiences (Northfield, 1998; Putnam & Borko, 1997); (3) knowledge is socially constructed, thus teacher educators should invest in building discursive communities of future teachers (Bell, 1998; Putnam & Borko, 1997). Unfortunately, still, the design of pre-service teacher educational programs has not been impacted by such a perspective (Northfield, 1998; Putnam & Borko, 2000). The creation of SCIED 410 represented part of an innovative effort to incorporate key ideas about learning into a pre-service education into a teacher education program for prospective science teachers.

One of the main difficulties in teacher learning is that, in spite of the extensive time spent in classrooms as learners, future teachers have rarely experienced the kind of learning that reform is promoting. If teachers need to develop subject matter knowledge and knowledge of subject-specific pedagogy for teaching science, how can science educators better situate and facilitate the development of this complex knowledge? From a situative perspective the answer to this question is: It must be situated in the context of the classroom. However, prospective teachers cannot, like practicing teachers, refer back to past experiences in their own classrooms and try new ideas with their own students. The closest parallel to those experiences would be student teaching (ST). ST has been identified as potentially the most significant experience in pre-service education. Ideally, during ST, knowledge accumulated throughout college is applied to classroom contexts (Northfield, 1998; Putnam & Borko, 1997). Nevertheless, little is known about how much future teachers learn during this late stage (Putnam & Borko, 1997), and PTs do not always have the opportunity to work in an appropriate context or even to teach through activities that are consonant with educational reform. More important, it appears that the gap between formal courses and school teaching is not necessarily challenged by the ST experience

(Northfield, 1998). There is evidence that future teachers hold structured knowledge and beliefs about teaching science that are built through their prior (and extensive) experiences as learners (see for instance, (Mellado, 1998). It is unlikely that such a complex knowledge structure will be changed during student teaching – even if that experience was exemplary. In other words, teacher educators should explore additional strategies to situate knowledge about teaching science in the classroom. Although student teaching is a valuable experience for future teachers, it is not sufficient to promote teacher development. Earlier in their education, PTs should be exposed to educational reform views, through experiences that take place in the context of classrooms, helping them to re-think their prior understandings (Northfield, 1998). In sum, it is essential that throughout prospective teachers' education, educators - including science educators - provide diverse contexts to situate knowledge in the classroom, starting as early as possible.

The impetus to develop a new course for Secondary Science PTs, SCIED 410, derived from a funded project aimed at integrating technology for supporting scientific inquiry into the Secondary Science Education program at our university, during the period of 1999-2000. This experience led to the development of the *Learning to Teach with Technology Model* (Friedrichsen, Dana, Zembal-Saul, Munford, & Tsur, in press). Through the process of implementation, the instructional team reflected on how to support teachers' leaning about central ideas in science education. The model derived from the project was conceptualized around elements of the conceptual change model, implying that for learning to occur, new knowledge has to be intelligible, plausible and fruitful. Thus, the phases of the model were conceived to gradually promote these conditions. In Phase I, PTs, as science learners, use technology tools to engage in scientific inquiry. This phase supports students in making knowledge intelligible, that is, they come to understand how technology affects science learning. In Phase II, PTs focus explicitly on the technology tool, learning how to use the tool (e.g., set up, trouble shooting). In Phase III, PTs examine existing technology-enhanced science curricula and/or modify exemplary curricula. In Phase IV, PTs use technology to support students' scientific inquiry in a supportive small group setting. Finally, in Phase V, in a school setting, PTs use technology to support students' scientific inquiry, using lessons that they design and implement. Reflection is embedded throughout all phases of the model.

SCIED 410 was designed to provide science learning experiences to PTs earlier in the program to facilitate teacher development. Students majoring in Secondary Science Education are required to take a sequence of three SCIED courses before student teaching. The first course, SCIED 410, is characterized as a science content course. At this stage, which parallels Phase I in the model, PTs engage in scientific inquiry as learners, reflecting mainly about two aspects of science teaching and learning: the nature of science and the nature of science learning. As we will describe later in this chapter, activities were designed to emphasize these themes. As Putnam & Borko (1997) put it, "because teachers are being asked to make considerable changes in the nature and content of classroom instruction, it is essential that they themselves experience these new visions of education as learners and then reflect on them as learning teachers." (p. 1286)

The other two courses, SCIED 411 and SCIED 412, are Science Teaching and Learning courses (i.e. methods courses). Thus, in these courses the emphasis shifts to developing teaching strategies to teach science, although the two themes mentioned above still receive much attention. At the end of the advanced methods course, PTs spend time in the school setting, first making observations, and then teaching (last five weeks). These three courses are completed prior to student teaching.

Overview of the Course

As we mentioned earlier, the course 'Technology Tools for Supporting Scientific Inquiry' (SCIED 410) is a science course developed specifically for secondary science education majors. PTs take the course prior to or concurrently with their first science methods course. In the first two semesters that the course was offered, however, it involved a more diverse group of education majors, including prospective elementary teachers.

SCIED 410 was designed and taught for two semesters by a team of 4 instructors: one professor and three doctoral students. The professor worked collaboratively with the graduate students in the design, implementation and revision of the course. As will be further described later, the course was composed of three modules, which focused on difference science disciplines (life, earth and physical sciences). Each of the modules had a lead instructor, one of the graduate students. The third author, who has background in Biology and extensive experience with both teaching high school science and science methods for PTs, was responsible for the Evolution Module. JT, who also has extensive experience with high school teaching, was responsible for the module on light, his area of expertise. Finally, the first author served as the instructor of the earth sciences module. Her background is in Biology and she has experience teaching high school and working with practicing teachers.

Focus on multiple disciplines

The course was structured around three modules (instructional units), focusing on life sciences (evolution), physical sciences (light) and earth sciences (global climate change). We purposefully chose to address different scientific fields for two major reasons.

First, we wanted to provide opportunities for PTs to experience at least one of the modules as learners. Given that prospective secondary science teachers major in a science discipline, we expected that they would be more knowledgeable about some modules (those most closely connected to their major) and less so about others. Many teachers do not have robust subject matter knowledge even in their areas of specialization; however, there may be strong resistance to engage as learners in experiences involving a content that you are supposed to know. Thus, learning content in other areas was intended to facilitate the process of being a learner of science.

Second, by having multiple disciplines represented in the course, we intended to address one particular aspect of the nature of science that is frequently neglected in school science: the common notion that there is a single 'scientific method'. This idea is rarely challenged in classrooms (Brickhouse, Dagher, Shipman, & Letts IV, 2000; Driver, Leach, Millar, & Scott, 1996; Rudolph & Stewart, 1998), despite the extensive evidence derived from science studies research (Hess, 1997; Knorr-Cetina, 1999). This course represented an effort to support teachers in better representing that aspect of nature of science in schools.

Doing Science as Argumentation

In each unit, PTs were confronted with guiding questions (e.g., Why so many finches died in Daphne Island in 1977? What happens to light after it leaves its source? Are global temperatures increasing?). It is not a new idea to adopt a question-driven or problem-based approach in science education. One of our major goals for using this approach in the course was to make the scientific concepts and practices part of an authentic context, meaning that learners would be engaged in ways that reflect what scientists do, as well as establish connections with their everyday lives (Brown et al., 1989).

As discussed earlier, knowledge tends to acquire 'inert' meanings when addressed in a more traditional way in classrooms. It has been reported that situated experiences help teachers to develop more robust science subject matter knowledge (Putnam & Borko, 1997). Thus, PTs investigated scientific problems in a rich and complex context. They collected data and, working in pairs, they constructed evidence-based arguments. Through argumentation, our students were expected to explore multiple explanations for a problem, provide multiple and relevant pieces of evidence to support their conclusions, make explicit how evidence and conclusions are related to each other, and recognize limitations and strengths in explanations that they build. At the end of the unit, PTs presented their conclusions to their peers. In sum, PTs engaged in all basic activities involved in 'doing scientific inquiry' in accordance with reform documents, with an emphasis in "science as argumentation" (National Research Council, 2000). It is worth noting that through that process we intend to make subject matter knowledge in science more problematic, that is, shift the focus of science learning from the 'answer' to the process (Hiebert et al., 1996).

It is worth noting that "science as argumentation" is seen as a way to improve science *learning*, which had important implications for how argumentation was conceived in the context of the course. First, in spite of the great influence of Toulmin's work, we rejected the idea of argumentation as debate on ideas *already developed* (e.g. (Toulmin, Rieke, & Janik, 1979); on the contrary, argumentation was seen as a continuous and dynamic process of knowledge construction as one (scientist or non-scientist) makes sense of his/her reality (Kuhn, 1991, 1992, 1993). This latter notion of argumentation also is particularly significant in light of the movement to make school science more authentic because argumentation is seen as an important part of scientific knowledge construction (Driver, Newton, & Osborne, 2000), as well as is considered a way of thinking that is fundamental for learners outside of school (Kuhn, 1991, 1993).

Constructing Knowledge Collectively

Moreover, these collective tasks reflected the authors' understandings of argumentation in the context of SCIED 410. Our work was guided by the view of argumentation as "dialogic reasoning", meaning that "Whereas problem solving, in the usual sense of the word, compels one to coordinate internal reasoning structures with some aspect of the physical world, … (argument) compels one individual to coordinate his or her reasoning structures with those of another individual." (Zeidler, 1997, p. 485). This perspective, taken in conjunction with Kuhn's perspective discussed previously, emphasizes the role of the social context in knowledge construction.

The notion of knowledge as socially constructed that has became increasingly prevalent in science education and teacher education literature (Kelly & Green, 1998; Putnam & Borko, 1997; Roth, 1995) was used to inform the design of course tasks. Although our current conceptions of knowledge, in general, and scientific knowledge, in particular, imply that it cannot be constructed in a social vacuum, school science normally portrays the process of knowledge generation as if it takes place in each individual's mind in an isolated manner (Driver et al., 1996). The image that emerges from these experiences not only is inaccurate in terms of how knowledge is constructed in "professional science" (Knorr-Cetina, 1999; Latour, 1987), but also fails to promote learning (Putnam & Borko, 1997). In fact, in those settings, scientific knowledge does not cease to be socially constructed, it just is constructed through a "social process" in which learners do not have a voice, and authority defines what counts as scientific knowledge. In SCIED 410, we attempted to create opportunities for science learners to collaborate with each other to construct scientific knowledge, with instructors' support.

Moreover, these collective tasks reflected the authors' understandings of argumentation in the context of SCIED 410. Our work was guided by the view of argumentation as "dialogic reasoning", meaning that "Whereas problem solving, in the usual sense of the word, compels one to coordinate internal reasoning structures with some aspect of the physical world, … (argument) compels one individual to coordinate his or her reasoning structures with those of another individual." (Zeidler, 1997), p. 485). This perspective, taken in conjunction with Kuhn's perspective discussed previously, emphasizes the role of the social context in knowledge construction, and our notion of argumentation embraces this aspect. Accordingly, argumentation is seen a process that facilitates learning because of it social nature (Pontecorvo, 1987).

Technology-Rich Environment

In SCIED 410, technology tools were used to assist PTs as they engaged in long-term investigations. These tools, specially designed to support scientific inquiry, provided access to complex databases, powerful analytical tools, tools for organizing data and constructing arguments, and access to complex scientific representations through visualization (Reiser, Tabak, & Sandoval, 2001). One fundamental aspect of the "situative perspective" is the distributed nature of cognition (Putnam & Borko, 2000). This notion implies that thinking does not occur in the mind of a single individual, but is distributed among other persons, as well as, tools that are part of the physical environment (Putnam & Borko, 1997). In this context, technological tools become pedagogical tools that have the potential to not only enhance cognition, but also transform it quantitatively (p. 1268).

Most of the technology tools in the course were developed by Northwestern University. In the Evolution unit, PTs used the software The Galapagos Finches, a rich scientific environment that provides scaffolding in the process of subject matter knowledge acquisition, and the development of domain-specific strategies for constructing scientific explanations in the field of evolutionary biology (Reiser et al., 2001). In the Light module (Bell & Linn, 2000), probeware and the software Data Studio from Pasco were used for data collection; and the software Progress Portfolio was used for argument construction. Progress Portfolio is a flexible environment designed to promote and support reflective inquiry, allowing students to record, annotate and organize products of an investigative project (Edelson, 2001). Finally, in the Climate Change unit, PTs used World Watcher, "a scientific visualization and data analysis program designed for learners" (p. 362); and Progress Portfolio to construct their arguments.

Learning about the Nature of Science

Following each unit, there were lessons in which PTs reflected on their experiences in the unit and made connections with fundamental concepts associated with the nature of science (e.g., what is theory and its role in science). To facilitate discussions, PTs did readings and engaged in activities that explicitly addressed the NOS. Those lessons were designed to support PTs in articulating their conceptions about nature of science and scientific inquiry in their philosophies. The focus was on the following aspects of NOS: role of theory, science as tentative, science cannot prove but can only disprove, and the influence of values and perspectives on scientific knowledge construction.

There is a consensus in the science education community that science teachers possess inadequate conceptions of the nature of science (Abd-El-Khalick & Lederman, 2000). PTs in particular, "showed themselves to be insecure and contradictory in answering questions on the epistemology of science, and recognized that they had not reflected before about these topics" (Mellado, 1998). Underlying the goal of helping PTs to develop better understandings of NOS is the assumption that such conceptions would influence their classroom practices. However, research has indicated that there is a complex relationship between teachers' conceptions of the nature of science and teaching practices (Abd-El-Khalick & Lederman, 2000; Lederman, 1992; Mellado, 1998). The major implication of these findings is that initiatives in the context of teacher education can be considered 'successful' only if teachers are able "to convey appropriate conceptions of the scientific enterprise to pre-college students" (Abd-El-Khalick & Lederman, 2000). In that sense, initiatives that were oriented by an *explicit* approach to NOS – in which inquiry-based activities are combined with activities that explicitly discuss aspects of NOS and support reflection – appears to be more effective than those that had addressed the issue implicitly. The explicit approach guided the design of the course.

Philosophy of Science Teaching and Learning

The other major task PTs had in SCIED 410 was to develop a web-based philosophy of science teaching and learning, in which they discussed their understandings of the nature of science and scientific inquiry, science learning, and the use of technology in science education. These ideas should be presented with supporting evidence derived from their experiences in the course. Their philosophy was revised after each of the modules, and at the end of the course PTs were asked to write a reflection on the changes their ideas underwent during the semester.

To see the learner as the one who actively constructs knowledge, instead of a passive receptor of information implies that learners must have opportunities to reflect and construct new meanings based on their experiences in the course. Moreover, it is important for learners to be able to recognize and make sense of the changes in their thinking throughout the course. The philosophy of science teaching and learning was designed to support learners in this process of reflection.

Reflections on Subject Matter Learning

In SCIED 410, PTs also reflected on their own learning. In each module, PTs were asked to comment on articles that discussed common alternative conceptions on the topics addressed in class (e.g. (Bishop & Anderson, 1990), research on evolution). As part of the assignment, PTs had to identify their own misconceptions, and discuss possible sources of alternative conceptions. In other words, in the same way we expected PTs to construct new understandings about teaching and learning science, we expected them to develop new understandings about subject matter knowledge in different disciplines. Again, we argue that as active learners PTs need to reflect about their own learning process. In this case, we focused on the recognition of limitations in their own subject matter knowledge, and the tenacity of misconceptions. These aspects should help teachers to see themselves as life-long learners with respect to scientific knowledge.

Implications for Practice

Finally, PTs were required to reflect on the implications of their experiences for teaching practice. They had to comment on articles that described experiences associated with teaching the topics being addressed in SCIED 410 to K-12 students, discussing how it would inform their own teaching and establishing connections between the article and class activities. This task, contrary to the others, was explicitly connected to the development of teaching strategies. The reasoning underlying it was that although PTs engaged in the course to experience a different way of learning science, it was important that they, as future teacher, reflect about how their experiences as learners would inform strategies for teaching science. Again, reflection is a key aspect in the process of developing new understandings, thus it was an essential part of the task.

Final Comments and Conclusion

K-12 science teachers are not the only ones to experience the challenges involved in engaging their students in "science as argumentation". Teacher educators also struggle with the difficulties of trying to reduce the gap that has separated theories and goals in science learning and our practices as science educators. This course represents an attempt to make these practices more coherent with our ideas and understandings about science teaching and learning. Nevertheless, the design of such a course goes beyond an effort to reflect those theories and goals, meaning that research in the context of SCIED 410 involved not only evaluating the extent to which goals were accomplished and teaching strategies "fit" our theoretical framework. Empirical research in this course has the potential to contribute to a better understanding of the very process discussed in learning theories, as well as to help us clarify aspects related to working in the specific context of *science* learning and with *future teachers*, in particular. In sum, we see the course as a setting that will permit us, as researchers, to refine our current knowledge about science learning and teacher learning (or teacher development).

Through qualitative research, various aspects have been explored so far in the context of SCIED 410. First, we are trying to learn more about how teachers engage in science learning and construct scientific knowledge through argumentation. Our approach to this issue involves interviewing participants, as well as observing and recording their interactions in class. Thus, we can better understand how PTs perceive and make meaning of these experiences in learning science. Second, we have been investigating how science learners use technology tools and how educators can better support them in the learning process. Finally, we have been able to identify limitations in PTs subject matter knowledge (both scientific concepts and understandings about scientific knowledge construction) and what activities/approaches/strategies appear to be particularly significant for conceptual development.

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EVALUATION OF A MODEL FOR SUPPORTING THE DEVELOPMENT OF ELEMENTARY SCHOOL TEACHERS' SCIENCE CONTENT KNOWLEDGE

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Since the release of the National Science Education Standards (National Research Council [NRC], 1996), there has been increased interest in implementing and sustaining inquiry-based science teaching. As school districts and their university and/or industry partners quickly discover, successful inquiry-based science programs require much more support for teachers than just the delivery of a kit full of materials (National Science Resources Center [NSRC], 1997). In addition to significant changes in pedagogy, teachers, particularly at the elementary school level, struggle with the increased demand for content knowledge required by the inquiry approach to teaching science. Because most elementary school teachers are not science content experts, they may hold some of the same misconceptions that their students do about the science curriculum (Schoon & Boone, 1998). In addition, inquiry teaching requires more understanding of and comfort with the content than is required by a more didactic teaching style (Carlsen, 1987; Dobey & Schafer, 1984). Thus, in thinking about how to sustain and improve inquiry science instruction, teacher educators need to consider ways in which to support the development of teachers' science content knowledge. Because efforts to teach science content in traditional university lecture-type courses has proved to be largely unsuccessful, even when accompanied by hands-on work (McDermott, 1997), new models for professional development are needed.

This paper provides a critical analysis of one such professional development model, which proposes to improve inquiry science instruction by addressing two components of teacher knowledge: pedagogy and science content. Although this represents an improvement over professional development models which focus on a single area of teacher knowledge, this paper will argue that, in order to impact inquiry science instruction, three pieces of teacher knowledge are required: pedagogy, science content, and pedagogical content knowledge (PCK) (Shulman, 1986). Without all three components, the impact on classroom instruction will be limited.

Description of the Model

The professional development model analyzed in this paper supports the development of teachers' science content knowledge by providing the experience of investigating a particular area of science content in an inquiry-based environment. Inquiry science teaching is expected to be improved through both increased content knowledge and teachers' authentic experience of learning science in an inquiry environment. The model is depicted in Figure 1.

Consistent with guidelines for effective professional development (Loucks-Horsley, Stiles, & Hewson, 1996), this model allows teachers to engage with a particular content area in a deep manner, over an extended period of time. Their learning is supported by a teacher-scientist pair who function as facilitators, providing (a) questions to investigate and (b) guidance in conducting and interpreting explorations based on these and the teachers' own questions. In this way, the facilitators model inquiry science pedagogy.

Although the blending of content and pedagogy is useful at any stage of teacher development, this particular model has been designed to address the science content needs of elementary school teachers who have been teaching inquiry-based science in their classrooms and would like to obtain a stronger understanding of the content of a particular curriculum unit. These teachers have, for the most part, a level of expertise characterized by the "use" of inquiry science materials (NSRC, 1997), and are struggling with how to translate the curriculum units into rich learning experiences for their students. Because the model provides teachers with opportunities to learn about science content directly aligned with that being presented to their students, it is expected that increased content knowledge will be directly applicable in the classroom, enabling teachers to better guide their students' investigations. However, the model contains no explicit connections to the elementary school classroom. In focusing only on teachers' learning of the science content and their experience of learning in an inquiry environment, the model excludes discussion of how this knowledge can be applied to teachers' work with their students.

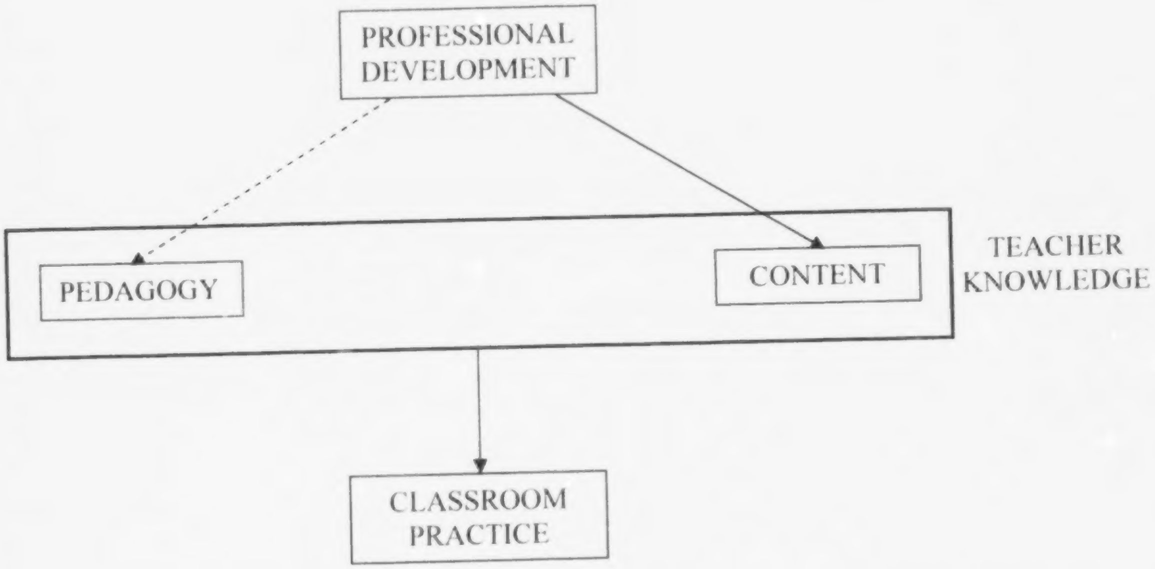

Figure 1. Diagram of professional development model. Direct influences (those explicitly included in the professional development experience) are depicted with solid lines, while indirect influences are depicted with dashed lines.

Theoretical Background for the Model

At its most basic level, this professional development model represents an attempt to interweave content and pedagogy (Post, 1997). It is patterned after the work of Duckworth, Easley, Hawkins, and Henriques (1990), who describe engaging teachers with "the real subject matter of science" and through this, a consideration of themselves and others as learners. As in the work of Duckworth and her colleagues, the content is adult-level science content related to topics taught in elementary school classrooms, while the pedagogy is inquiry pedagogy, or (in Duckworth's case) constructivist pedagogy. Thus, teachers learn in an environment similar to that which they are expected to create for their own students. Although there is often a disconnect between the form and content of professional development programs, in addition to common-sense arguments, this more-encompassing model is well-supported in the research literature (e.g. Shavelson, Copeland, Baxter, Decker, & Ruiz-Primo, 1994).

The mixing of content and pedagogy addresses two key issues which are included in this professional development model. First, although teachers' increased content knowledge is a useful objective by itself, the more pressing goal is improving the effectiveness of teaching for students. Increased content knowledge has limited utility if it is used to create a longer list of facts to impart to students. Rather, it is the combination of solid inquiry pedagogy with increased content knowledge that is needed. Second, inquiry pedagogy, which has roots in the constructivist tradition, has been shown to be effective for both children and adults (NRC, 1999). Therefore, this is a viable framework for the development of teachers' science content knowledge. In particular, teachers are given the opportunity to build upon their previous conceptions of the science content by designing their own explorations and constructing their own explanations, with guidance from both a fellow teacher and a scientist.

Implementation of the Model

This paper focuses on a particular implementation of this model, a course entitled Floating & Sinking (Alonzo, Hartney, Linden, Post, & Stewart, 1997). It was designed according to the components of the professional development model described above. The course addresses the science content contained in the Clay Boats unit (Elementary Science

Study, 1996), part of the district-wide curriculum for third graders at the schools in this study. The Clay Boats unit engages students in initial explorations of concepts related to floating and sinking, through the construction and testing of boats made out of materials such as clay, foil, and waxed paper. The Floating and Sinking course provides teachers with the opportunity to engage in an in-depth exploration of concepts related to density for a total of 24 hours.

The Floating & Sinking module begins with an elicitation of teachers' prior knowledge and an activity in which they predict and test whether a variety of household objects will float or sink when placed in water. Next, teachers explore the question, "What variables affect floating and sinking?" This is followed by investigations of both weight and water displacement. Teachers return to the task of predicting floating/sinking behavior by using the results of their previous inquiries to make predictions about mystery cylinders. Next, they consider floating/sinking behavior in liquids other than water. Finally, they rely on all of their investigations to invent a definition of density and explain its role in determining whether an object will float or sink.

Method

The work described in this paper is part of a larger study to examine the effects of the Floating & Sinking course on teaching and learning in the Clay Boats unit. Of particular interest in evaluating the professional development model is data related to teachers' content knowledge and its effects on classroom inquiry science instruction. Although the larger study included teachers who were not part of the Floating & Sinking professional development experience, this paper will focus exclusively on the seven teachers who participated in the course.

Before and after the Floating & Sinking course, each teacher completed an extensive paper-and-pencil assessment of her content knowledge related to floating and sinking. An additional content question was included in an interview conducted before the teachers taught the Clay Boats unit each year. See the Appendix for content knowledge questions considered in the following analysis. These questions were developed through consideration of (a) knowledge of floating and sinking required to fully explain phenomena encountered in the Clay Boats unit and (b) common misconceptions about floating and sinking, as revealed in the research literature (e.g. Biddulph & Osborne, 1983) and observations in the first year of the study.

Because the study spanned two years, teachers were observed teaching the Clay Boats unit twice: once before and once after their participation in the Floating & Sinking course. While they were teaching the unit, three to five observations were conducted, including extensive field notes and audio-tapes, which were subsequently transcribed. The observation piece of this study allows a unique perspective on the effects of science content knowledge on inquiry science instruction. Although there have been a few studies which document the effect of science content knowledge on pedagogy (e.g. Carlsen, 1987), to our knowledge, there have been no studies which examine the effects of content knowledge on the science content which is presented to students. In this study, such analysis is possible, including documentation of the misconceptions teachers presented to their students.

Results

Teachers' growth as a result of the professional development program Floating & Sinking can be examined along two dimensions: content knowledge and use of content knowledge in instruction.

Trajectories for Growth in Content Knowledge

In order to document how teachers' content knowledge changed as a result of their participation in the Floating & Sinking course, an analysis of teachers' answers to content knowledge questions was conducted and described along a continuum of knowledge about floating and sinking. This analysis focused on the knowledge required to fully explain phenomena encountered in the Clay Boats unit. In particular, the final stage of the trajectory (Level 4) is exemplified by the ability to generate a complete explanation of why boats float, as indicated by the interview question and the "clay ball" question. This requires making the connection between the concept of density and the phenomenon of floating boats, and represents the most complicated instance of floating: an open object. At a slightly lower level of understanding (Level 3), teachers can explain the floating/sinking behavior of the most complicated closed objects, hollow objects. This understanding is demonstrated by teachers' explanations of the role of air in floating and sinking in terms of how air affects the density of an object (the "air" question). At Level 2, teachers provide a definition of density (the "density" question) and identify its role in the floating/sinking behavior of the solid objects (the "mystery cylinder" and "material" questions). Teachers at Level 1 do not recognize the crucial role of density in floating and sinking. Instead, they cite various factors related to floating and sinking to explain whether an object will float or sink. Finally, Level 0, the beginning of the trajectory, represents a point at which teachers hold major misconceptions about floating and sinking. For example, a common misconception was the belief that the amount of water is a crucial factor in determining whether an object will float or sink (the "amount of water" question).

Content knowledge trajectories for each of the seven teachers are represented in Figure 2. In order to illustrate these trajectories, the cases of Ms. Innes, Miss Florillo, and Ms. Oren are described in detail below.

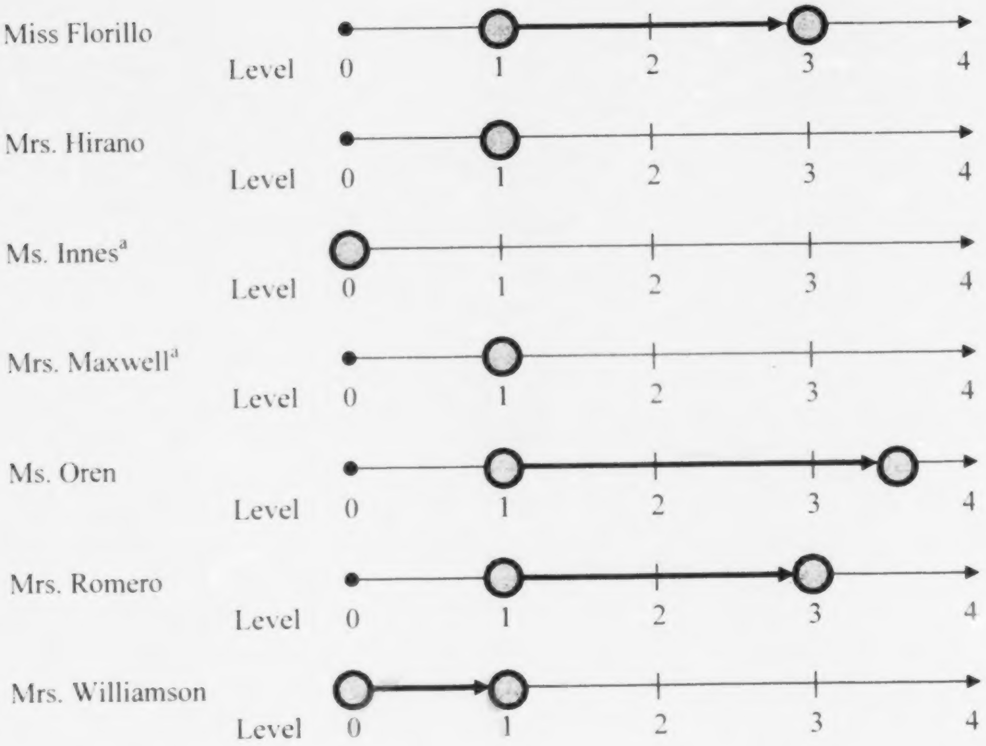

Figure 2. Trajectories for Growth in Content Knowledge.

[a] Content knowledge information obtained only through initial content knowledge assessment, interview, and classroom observation.

Ms. Innes

Both before and after the Floating & Sinking course, Ms. Innes did not make a connection between her precise definition of density and the phenomenon of floating boats. In both years, her explanation for boats' ability to float included surface area, the distribution of weight, and the amount of water. In addition to data from the interview, classroom observations revealed that Ms. Innes retained two misconceptions after the Floating & Sinking course. She strongly believed that larger amounts of water would increase a boat's ability to float (even if the boat were not touching the bottom of the container). In both years, she had students conduct an investigation in order to prove this. In addition, she guided students towards an understanding that the material cargo was made of (not its weight) was crucial in determining the how much cargo a boat could hold. Significantly, despite some substantial misconceptions about floating and sinking, Ms. Innes was viewed as the science content expert by the other participants in the Floating & Sinking course, so that her incorrect ideas were often accepted as truth by the other teachers.

Miss Florillo

Before the Floating & Sinking course, Miss Florillo had vague ideas regarding floating/sinking phenomena. In describing a strategy for predicting whether a mystery cylinder would float or sink in water, she explained that she would place the cylinder in a different liquid (the "mystery cylinder" question). However, this was not related to density or to any other property of the object or liquid. To explain why a piece of clay can float when shaped as a boat (the "clay ball" question), she said, "It has to do with the surface area and density of the clay." However, later in the interview, she said that she didn't really know what density means. She recognized that density and weight are different but could not explain their relationship (the "density" question). Miss Florillo was aware that it was possible for solid objects to float and thought that air played a role in determining floating/sinking behavior. However, she did not understand how air influenced whether an object would float or sink. Her response to the interview question involved explaining the phenomenon of floating boats in terms of surface area and weight distribution.

After the Floating & Sinking course, Miss Florillo articulated a correct understanding of the role of density in determining whether solid objects will float or sink (the "mystery cylinder" question). She also gave a complete explanation of the role of air in the floating/sinking behavior of hollow objects in terms of the effect of air on an object's density (the "air" question). However, when discussing boats in the interview question, her explanations relied solely on her previous ideas about surface area and weight distribution . Interestingly, her newly-acquired definition of density (the "density" question) was expressed in terms of weight per square unit. Perhaps this was a means of reconciling new information about the critical role of density in floating and sinking with her intuitive sense that surface area was an important factor.

Ms. Oren

Before the Floating & Sinking course, Ms. Oren had a solid foundation for understanding the concept of density. She defined density as weight per square unit and described a strategy for predicting whether a solid object would float by an indirect density comparison. In answer to the "mystery cylinder" question, she said, "I can weigh the cylinder. I can compare the weight to a cylinder of the same size that does float. I would compare its weight to its size." Her explanations for floating hollow objects and boats involved weight distribution and surface area.

After the Floating & Sinking course, Ms. Oren's answers revealed the co-existence of her old ideas, along with new information obtained from the course. Her answer to the "mystery cylinder" question involved a precise and detailed explanation of the role of density (of both object and liquid) in determining the floating/sinking behavior of solid objects. However, in response to the "density" question, she restated her original definition for density, involving square units, but used volume units in an accompanying example. This seems to indicate either confusion between volume and area or a failure to differentiate between the two.

To answer the "air" question, Ms. Oren gave a clear explanation for the role of air in floating and sinking. She wrote, "Solid objects also can float when you change the shape which therefore changes the volume. Air becomes part of the volume." Although this explanation could also be used in considering the phenomenon of boats' floating, Ms. Oren's response to the "clay ball" question revealed that she had not yet made this extension. She relied on her old ideas about weight distribution to explain how a clay boat can float.

Her answer to the interview question also revealed a mixture of old and new ideas. She listed both density and the distribution of weight as factors affecting a cruise ship's ability to float. And later in her answer, she said, "Air is part of the mass, and so that changes the whole density of, well, it changes the, it's a variable that affects if something's going to float or not." While she seems to have a tentative understanding of density and its role in floating and sinking, this has not completely replaced her ideas about weight distribution and surface area.

Trajectories for Use of Content Knowledge in Instruction

The analysis of teachers' use of content knowledge in their teaching of the Clay Boats unit focused on an examination of the transcripts of classroom discussions, as well as a more general look at the science content presented each year. Any indication of teachers' use of content knowledge, particularly questions and dialogues with students, was culled from the transcripts. In addition, lessons and other direct importations from the Floating & Sinking course were noted.

Several types of content knowledge use were observed, representing various levels of pedagogical implementation. At the final stage of the trajectory (Level 3), teachers made extensive use of their content knowledge to guide students' learning. Ms. Oren exemplified this level of content knowledge integration, by consistently questioning students' statements about the role of weight in floating and sinking, suggesting that students consider additional factors in floating/sinking behavior, and designing inquiries for students to explore their ideas about weight. Teachers at Level 2 also incorporated science content knowledge into their classroom; however, this represented direct instruction: telling students facts about floating and sinking, rather than using content knowledge to guide students to their own understanding of the concepts. Level 1 represents an effort to incorporate science content knowledge to guide students' learning. However, there are limited examples of this type of dialogue or questioning present. At Level 0, there is no evidence of the use of content knowledge. Evidence from the Floating & Sinking course is limited to the direct importation of lessons from the course.

For each of the seven teachers, trajectories for the use of content knowledge are represented in Figure 3. The trajectories reveal no change in how teachers used content knowledge in their instruction, although two teachers (Mrs. Maxwell and Ms. Innes) did incorporate more content knowledge into their pre-existing teaching strategies. In order to illustrate these trajectories, the cases of Mrs. Hirano and Mrs. Maxwell are described below.

Mrs. Hirano

The main influence of the Floating & Sinking course in Mrs. Hirano's classroom seemed to be the incorporation of a lesson directly from the course. She had her students predict and test the floating/sinking behavior of a variety of household objects, including many of the same ones used in the course. However, this was not used as a starting point for getting students to think about factors involved in floating and sinking. The activity remained isolated from the rest of the Clay Boats lessons.

In both years, there were rare examples of Mrs. Hirano's use of content knowledge to guide student thinking. In year one, Mrs. Hirano encouraged her students to think about bigger boats holding more cargo, but this seemed to be related to the room inside the boat, rather than to any consideration of the density of bigger and smaller boats. During the lesson involving

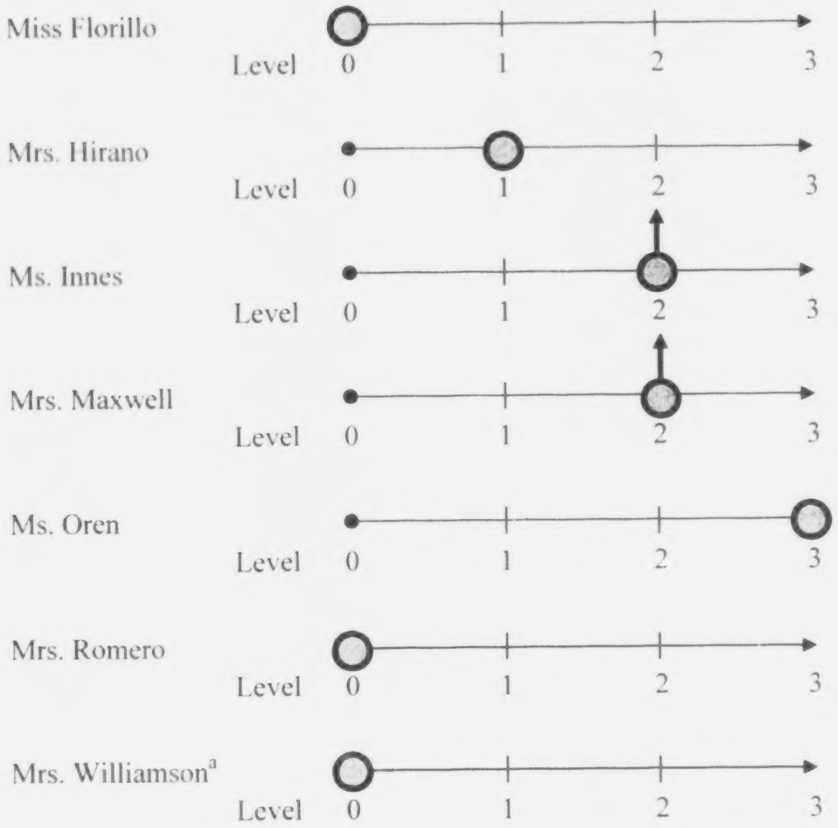

Figure 3. Trajectories for use of content knowledge in instruction. The horizontal axis represents the use of content knowledge dimension, while vertical arrows indicate increases in the content knowledge evident during instruction.

[a] No pre-course observations available.

household objects, there were two separate dialogues in which Mrs. Hirano focused students' attention on the role of weight in floating/sinking: one which emphasized the importance of weight and one which questioned the importance of weight. The former dialogue occurred after students observed an empty film canister floating and Mrs. Hirano asked students to predict what would happen if she added a marble to the film canister:

> Students: Sink!
> [Mrs. Hirano adds a marble to the film canister, but it still floats.]
> Student: It gained weight.

Student: It's floating.
Mrs. Hirano: Did the weight matter? What will happen if I add more marbles?
Student: It will sink.

Although Mrs. Hirano seemed to be pointing students in the direction of considering weight, she did not use her content knowledge to follow through with this dialogue.

Mrs. Maxwell

Mrs. Maxwell imported two lessons directly from the Floating & Sinking course and introduced the definitions of floating and sinking that she had learned. Like Mrs. Hirano, she repeated the lesson on predicting and testing whether household objects would float or sink in water. In addition, she tried to repeat the lesson on water displacement with her students. In the Floating & Sinking course, she had measured the volume of water displaced by various floating and sinking objects and compared this to (a) the volume of the sinking objects and (b) the weight of the floating objects. However, without the graduated cylinder or triple beam balance used in the Floating & Sinking course, she was not able to demonstrate these relationships to her students. She tried to engage students in measuring water displacement, by recording the water level in a small cup with a piece of masking tape. However, from discussions during this activity, it was not clear that her students understood what she meant by water displacement. She appeared to have difficulty in translating her experience into something that third graders could understand, particularly without the equipment she had used in the course.

Mrs. Maxwell used content knowledge from the unit to supplement her existing teaching strategy. In both years, she relied on song lyrics to "explain" floating and sinking: "What makes an object float/Reasons there are three/Surface tension, weight displaced, and lesser density." In year two, she added information from the Floating & Sinking course to the definition of water displacement she presented to her students, telling them that the weight of water displaced is equal to the weight of the floating object. However, she seemed to be referring to the weight of the cargo in students' boats, rather than that of the entire object (boat plus cargo). In year one, Mrs. Maxwell treated density as something obvious and not worth defining. In her paper-and-pencil assessment before the Floating & Sinking course (the "density" question), she revealed that this was probably because she didn't have a definition of this term herself. In year two, she attempted to define density for her students, but her explanation was a bit confused, and the example she used to illustrate the concept confounded weight, volume, and density.

General Teacher Change Patterns

Examining the trajectories of these seven teachers, some patterns emerge. Not surprisingly, change in teachers' content knowledge was greatest for those concepts directly addressed during the Floating & Sinking course, either through direct investigation or discussion. The greatest improvement was observed for teachers' understanding of general rules for floating/sinking of solid objects, the role of air in floating/sinking behavior, and water displacement. All three of these topics received extensive coverage in the Floating & Sinking course. However, these new ideas co-existed with old ideas which were unchanged by the course. Teachers who were able to give clear explanations of density and its role in solid objects' floating/sinking behavior, often reverted to explanations involving surface area or weight distribution when explaining why boats float. This was sometimes accompanied by alternative definitions of density, which involved square units, rather than volume.

Other teachers had less well-developed understandings of density by the end of the Floating & Sinking course. They did not seem to recognize the critical role of density in floating and sinking, and continued to list a variety of factors related to floating and sinking. Although there was some change in the factors mentioned (for example, a decreased emphasis on weight), these were not related to density as an overarching concept in floating/sinking. In addition, when ideas from the course were mentioned, these tended to be repetitions from the course, rather than expressions of ideas in the teachers' own words.

The most common effect of the Floating & Sinking experience was for teachers to try to import lessons and/or information from the course directly into their third grade classrooms. In general, there was very little evidence of any use of content knowledge in guiding students' inquiry experiences.

Discussion

The results presented above have implications for revising the professional development model on which the Floating & Sinking course was designed, both to improve teachers' content knowledge growth, and to improve their use of that content knowledge in elementary school classrooms.

Model Revision for Improved Content Knowledge Growth

As currently designed, the Floating & Sinking course starts with an exercise intended to elicit teachers' pre-existing ideas about floating and sinking. As is common in elementary school classrooms, this takes the form of a "KWL" chart, asking the participants to list what they know ("K") and what they want to know ("W"), with the expectation of returning later to fill in what they have learned ("L"). However, the results detailed above indicate that this is not enough. Teachers' misconceptions may not be elicited by a KWL chart. Instead, specific questions, such as those included in the paper-and-pencil assessment, must be asked and analyzed to determine teachers' pre-existing ideas. The results show that this form of professional development may be effective in changing teachers' content knowledge, but only in areas explicitly addressed.

Teachers in this study explained the phenomenon of boats' floating with surface area and weight distribution both before and after the Floating & Sinking course. Although some teachers gained an understanding of the role of density in floating and sinking, and several were able to explain how forming a boat shape from a ball of clay represented a change in density, these new ideas co-existed with their previous ideas about surface area and weight distribution. Without direct discussion of surface area and weight distribution, these explanations retained their salience for the teachers.

Perhaps related to co-existence of explanations involving both surface area and density, teachers did not seem to have a clear understanding of the distinction between area and volume, before or after the Floating & Sinking course. Throughout the course, density was defined using volume, but this was never directly contrasted with area, so that some teachers continued to use volume and area interchangeably.

Finally, the Floating & Sinking course never explicitly addressed the issue of the amount of water. Ms. Innes, viewed as the content expert by her colleagues, had a strongly-held belief that a boat would float "twice as well" in twice as much water. As this was not explicitly addressed in the course, she retained this belief. In fact, it is possible that she influenced other teachers, such that they also held this belief by the end of the course.

Model Revision for Improved Use of Content Knowledge: Specifying Intended Impact

The tendency of teachers to directly import lessons from the Floating & Sinking course into their classroom is not surprising, given the usual science professional development that is offered to elementary school teachers. All of the teachers in the study had received school-district-provided training in how to use the inquiry-based science kits that constituted the district's elementary science curriculum. They received one day-long training for each of the four kits in the curriculum at their grade level. During these training sessions, teachers engage in the unit as if they were the students in their class. The teacher facilitator acts as the teacher, occasionally interjecting management tips into the training. But, the general idea is that teachers will have experienced the unit as their students will. They will then take the lessons that they experienced (acting as students) and teach them in their classrooms.

The professional development model described here is a significant departure from these training sessions in the way in which the experience is expected to be used in the classroom. Rather than using specific lessons with their students, the model assumes that the impact on classroom instruction will require an additional level of transfer. The expectation is that teachers will apply the pedagogy they have experienced without directly applying the experiences themselves. In addition, a further level of transfer is required in that the teachers are not expected to directly teach the content knowledge that they acquired through these activities to their students, but rather to use this knowledge to guide their students in activities only peripherally related to what they experienced during the Floating & Sinking course.

However, discussion of how the professional development experience is expected to influence classroom instruction is entirely absent from the professional development model. Without a competing model for how to use the experience in their classrooms, it is reasonable that teachers will use the model with which they are familiar: using the content of the professional development directly in their classrooms. Although the teachers were repeatedly told that "this is only for you, not for your students," they were all interested in the course because they wanted to teach the Clay Boats unit more effectively. Therefore, in the absence of any other explanation of how the Floating & Sinking course was intended to influence their classroom instruction, they borrowed lessons from the course for use with their students.

The professional development model needs to be revised to include explicit discussion of what the experience is expected to provide for teachers and how this is expected to influence their work in the classroom. The effectiveness of the model is drastically reduced when teachers are expected to make these connections without any guidance.

Model Revision for Improved Use of Content Knowledge: Incorporating PCK

Most teachers showed little or no evidence of incorporating content knowledge into their inquiry science instruction. This seems to be related to their understanding of inquiry pedagogy as being "content-free." A separate analysis of data from the larger study (Alonzo, 2002) reveals that most teachers expressed the view that inquiry means "not telling the students the answers." This understanding does not include moving students towards "the answers." By focusing on the "not telling" part of inquiry pedagogy, teachers are missing the crucial role of the instructor in guiding students to an understanding of the science content. But, in fact, many teachers did not view learning science content as a primary goal of elementary school science. Therefore, a discussion of the science content goals of the Clay Boats unit may be a useful starting point for exploring how teachers' content knowledge might be used to guide students to an understanding of this content.

Although the facilitators of the Floating & Sinking course used their content knowledge to guide the inquiry experiences of the participating teachers, this was not explicitly addressed. Because the use of content knowledge is something that goes on in the facilitators' heads, merely modeling inquiry pedagogy does not allow the participants to understand how content knowledge is used to guide inquiry. Therefore, the teachers were able to experience learning in an inquiry environment, without understanding all that is required to create and sustain such an environment. Explicit discussion of how science content knowledge is used generally in inquiry science pedagogy and more specifically in investigations related to the Clay Boats unit are critical to ensuring that the professional development experience has significant classroom impact.

For those teachers who attempted to move beyond direct importation of lessons, to use the content knowledge from the Floating & Sinking course in their classrooms, a further barrier was encountered. Even those who had gained a significantly greater understanding of the adult concept of density were unable to relate this to their third graders in an effective manner. During the Floating & Sinking course, there was very little discussion of the relationship between the content of the course and that of the Clay Boats unit. Therefore, teachers were largely left to make this connection themselves, with varying results.

Since teachers' primary motivation to participate in professional development stems from a desire improve what happens in their classrooms, it makes sense to include the relationship to the classroom as an essential component of their experience. However, this professional development model neglects this crucial piece by focusing only on teachers' content and pedagogical knowledge. The missing connection to the classroom is pedagogical content knowledge (PCK), which details how content knowledge can be used in conjunction with inquiry pedagogy to further students' learning.

Therefore, the professional development model described in this paper (and depicted in Figure 1) must be revised to include pedagogical content knowledge. A sketch of this new model is shown in Figure 4.

Conclusion

The need for professional development for inquiry science is acknowledged by the National Science Education Standards: "The current reform effort requires a substantive change in how science is taught; an equally substantive change is needed in professional development practices" (NRC, 1996, p. 56). However, clear research on effective models of professional development are crucial for this effort.

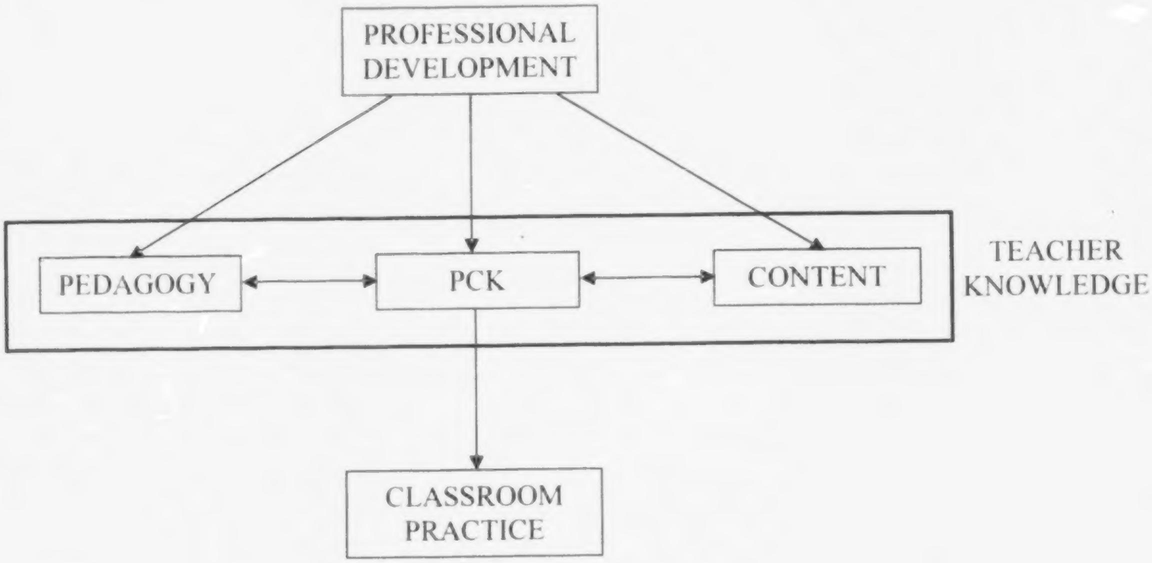

Figure 4. Diagram of revised professional development model.

This study represents an effort to evaluate one proposed model of professional development: a blending of content and pedagogy. However, the results indicate that it is not enough to provide science content knowledge in an inquiry-based learning environment. Teachers must be aware of the professional development model and how it is expected to impact their classroom work. Even more critically, teachers' pedagogical content knowledge (Cochran, 1992; Shulman, 1986), the bridge between pedagogy and content must also be addressed. Therefore, a new model is needed which incorporates these three aspects of teacher knowledge: pedagogy, content, and pedagogical content knowledge.

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Appendix

Selected Floating & Sinking Items

Interview Question

Suppose a student asks you why cruise ships float when they are so heavy. What sort of explanation would you give to him/her? (Plus a follow-up question: Would your answer be different if you were speaking to a colleague?)

Pre-/Post-Course Assessment Questions

1. Suppose you have been given a solid cylinder of gallium arsenide. How many different ways can you think of to determine if this cylinder will float in water? The only restriction is that you may not place the cylinder in water. [The "mystery cylinder" question.]

2. One of your colleagues says that he doesn't understand why changing the shape of a piece of clay can allow it to float since it is still the same material. How would you explain this to him? [The "clay ball" question."]

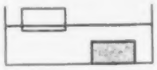
3. Another colleague explains that one of her students was convinced that his boat would have floated if he had more water in his container. Because it was the end of the lesson and she doesn't have a sink in her room, the teacher didn't pursue this issue with the student. However, now she has been thinking about whether the amount of water makes a difference and is wondering why or why not. How would you respond to answer her question? [The "amount of water" question.]

4. Two teachers have been discussing how to determine if something will float or sink. One teacher says that he has heard that density has something to do with floating and sinking. Another teacher says that weight determines what will float and what will sink, and adds that she thinks density is just a fancy word for weight. Both teachers agree that they don't really have a

clear idea about what density means. What would you say to help them sort this out? [The "density" question.]

5. A final colleague says that she is confused about the role of air in floating and sinking. Her students have been mentioning air as an important factor, but she thinks that it is possible for a solid object to float. How would you explain this to her? [The "air" question.]

6. This is what happens when you place a block of wax (☐) and a block of aluminum (▨) in the water…



Suppose you have…

1) a large block of wax which weighs more than the original block of aluminum and

2) a small block of aluminum which weighs less than the original block of wax.

For each block… What would happen if you placed it in the water? (Check one.)

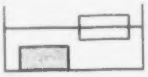
____ It would definitely float.

____ It would definitely sink.

____ There is not enough information to determine if it will float or sink.

[The "material" question.]

7. Suppose you have two blocks of identical size, but made from different materials. As shown, one block sinks, while the other one floats half above, and half below the water.



For each block… What would happen to the water level in the container if the block were removed from the water? (Check one and describe.)

____ The water level would remain the same.

____ The water level would go up, by an amount determined by...

____ The water level would go down, by an amount determined by...

[The "water displacement" question.]

GETTING TO THE FOURTH YEAR: THE INSTRUMENTS AND PROTOCOLS USED TO STUDY THE PRACTICE OF BEGINNING K-12 SCIENCE TEACHERS

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Beginning Science Teacher Study

Getting to the Fourth Year is a study being conducted by the Teacher Research Network (TRN) in Minnesota. The TRN was established in 1998 by five higher education institutions that collectively prepare about seventy five percent of all K-12 teachers in the state. The TRN is a project of the Transforming Teacher Education Initiative (TTE). The Transforming Teacher Education Initiative, a group of Minnesota faculty from higher education and K-12 schools, was developed to work with state policy makers in aligning state and national standards for K-12 students and teachers. The vision of the collaborative was to begin the process of transforming teacher education in mathematics and science so that teachers will be prepared to 1) teach according to the vision of present and future national standards and 2) continue learning new content and new ways of teaching throughout their professional career. The TTE is a division of SciMath^{MN} that provides the funding for this TRN study. Dr. George Davis from Minnesota State University Moorhead and Dr. Patricia Simpson from St. Cloud State University serve as co-directors of the Teacher Research Network.

SciMath^{MN} is a statewide, public/private partnership that was incorporated in 1993 to work in Minnesota to increase the educational achievement and participation of all Minnesota students in science and mathematics. It has done so by promoting standards-based policy, professional development and practice; and, public awareness and engagement. SciMath^{MN} staff serve as project managers within each of these areas. Bill Linder-Scholar is the Executive Director of SciMath^{MN}.

The primary purpose of TRN was to devise a plan of study and instruments to assess the current status of our beginning mathematics and science teachers that we define as those in their first three years as teachers. Additionally, TRN encouraged the collaboration of science and mathematics education researchers and provided those researchers with financial support and on-going professional development opportunities.

Purpose of Study

The TRN Study project was established to collect information about the practice of beginning K-12 science and math teachers in Minnesota in their first three years of teaching. Minnesota has seen a high percentage of beginning science and math teachers drop out of teaching during their first three years of teaching. The study looks to determine what factors might be causing this high drop out rate. Specifically the research questions of the study are:

- What are new teachers' current practice, knowledge and beliefs about teaching science/math?
- What is the context in which new teachers teach science/math?

Origins of the Study

As a result of SciMath^{MN}'s participation in the Salish II project, five teacher preparation institutions came together to explore the possibility of a joint study into the practice of Minnesota's beginning teachers of science and mathematics. From this initial meeting TRN was established and funded by SciMath^{MN}. The Teacher Research Network met several times during its first year to investigate the research process used by Salish I and II and their findings, as well as other scholarly work related to teacher assessments. These included the Interstate New Teacher Assessment and Support (INTASC) portfolio project and the Praxis exams used by our state. From these existing investigations and instruments came the current protocols and study instruments used by TRN.

Operation of the Study Network

Currently, the TRN group meets two to three times a year. The meetings provide an opportunity for researchers to discuss the use of the instruments, their findings and raise questions and concerns about the study protocols. Discussions have centered on each instrument, how it has worked, the results, what the results tell us about our research questions and whether or not modifications are needed in instruments or procedures. When instruments are changed, training on the instruments and their analyses are provided at the meetings. Lately, discussions about the analysis and reporting of study findings are common. Meetings are also a time for professional development related to issues associated with research on teaching and learning. Each university is required to send representatives to these meetings and ensure that all university team members understand what is to be done.

Each participating university has a team composed of full-time faculty at the teacher preparation institution. Each team has a contact person who is responsible for the efforts of their institution and for maintaining communication with the directors of the project. All TRN members serve as researchers investigating beginning

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science and mathematics K-12 teachers. Members may also choose to serve the TRN collaborative as members of special interest groups. These groups work on development of individual instruments, compilation of data, or interpretation of data. Institutional teams apply annually to SciMath^{MN} for grants to financially support the work being done by their team members. Grants primarily support participating teacher stipends, travel, materials costs and transcription fees. SciMath^{MN} also provides support to the network as a whole for TRN meetings, speakers, staff and other resources necessary to keep the network running.

University teams agree to the use of a common set of instruments and procedures chosen for use each year. Every team collects data from individual teachers, no more than two teachers per researcher, as outlined by the network's study procedure and returns the data to the special interest groups responsible for its analysis. Once the common research goals of the organization are met, individuals or teams may additionally choose to investigate additional research questions by using the same instruments with other student populations. Currently the TRN network includes ten institutions. The initial five universities (Minnesota State University Moorhead, St. Cloud State University, University of Minnesota Duluth, Gustavus Adolphus College and St. Mary's University) have been joined by five other teacher education institutions (The College of St. Scholastica, St. Thomas University, Winona State University, Minnesota State University-Mankato, and the College of St. Benedict/St. John's University). During the 2000/2001 academic year, faculty at each institution administered four instruments to mathematics and science teachers in their first, second or third year of practice. Approximately 50 K-12 teachers participated in the project.

Study Instruments

The CLES 2(20), Modified Constructivist Learning Environment Survey, was modified from the Constructivist Learning Environment Survey (CLES). The CLES was developed "... to enable teacher-researchers to monitor their development of constructivist approaches to teaching school science..." (Taylor, Dawson, & Fraser, 1995, p.1). Originally developed by Peter Taylor and Barry Fraser at Curtin University of Technology in Perth, Australia (Taylor, Fraser, & Fisher, 1993) the CLES consisted of 28 items, seven each in four scales - autonomy, prior knowledge, negotiation, and student-centeredness. The instrument was later revised to incorporate a critical theory perspective because "... our ongoing research program had revealed major socio-cultural constraints (e.g., teachers acting in accordance with repressive cultural myths of cold reason and hard control) that worked in concert to counter the development of constructivist learning environments." (Taylor, et al., 1995, p. 2).

The revised CLES was used in the first year of this study consists of 30 items, six each in five scales (see Table 1). Rather than having items from different scales mixed together throughout the instrument, items in this version are grouped by scale. In addition, there is only one item that is negatively worded. The items attempt to reveal teachers' perceptions of the learning environment in their classrooms. Versions for both science teachers and for their students were produced.

Table 1

Constructivist Learning Environment Survey CLES Scale Descriptions

Personal Relevance -

"Extent to which school science/mathematics is relevant to students' everyday out-of-school experiences."

Uncertainty -

"Extent to which opportunities are provided for students to experience that scientific/mathematical knowledge is evolving and culturally and socially determined."

Critical Voice -

"Extent to which students feel that it is legitimate and beneficial to question the teachers' pedagogical plans and methods."

Shared Control -

"Extent to which students have opportunities to explain and justify their ideas, and to test the viability of their own and other students' ideas."

Student Negotiation -

"Extent to which students share with the teacher control for the design and management of learning activities, assessment criteria, and social norms of the classroom."

Note: All scale descriptions are taken from: Taylor, Fraser, & Fisher, 1997.

Exploratory factor analysis and internal consistency (alpha) reliability, as well as examination of each item and of participants' questions and comments about them, led to the development of a revised survey (Johnson, 1990), renamed the Constructivist Learning

Environment Survey 2(20) [CLES2(20)]. The revised survey retains the same five scales included in the CLES but reduces the number of items from 30 to 20, four in each scale. In addition, several items were reworded or replaced with new items. The sole negatively worded item was replaced with a positively worded item. Items were grouped by scale as in the CLES.

In this study, we use the CLES2(20) with both science teachers and with their students. Each teacher who participates in the study completes the appropriate teacher form, giving us a picture of how he or she views the classroom environment in his or her own classroom. At the same time, the teachers' students complete the student form, giving us the students' perceptions of the classroom environment.

The results that we get from the CLES2 (20) are a source of information for use, along with classroom observations and teacher interviews, in writing teacher profiles (Davis & Simpson, 2000). The five CLES2 (20) scales align with teacher profile categories as shown in

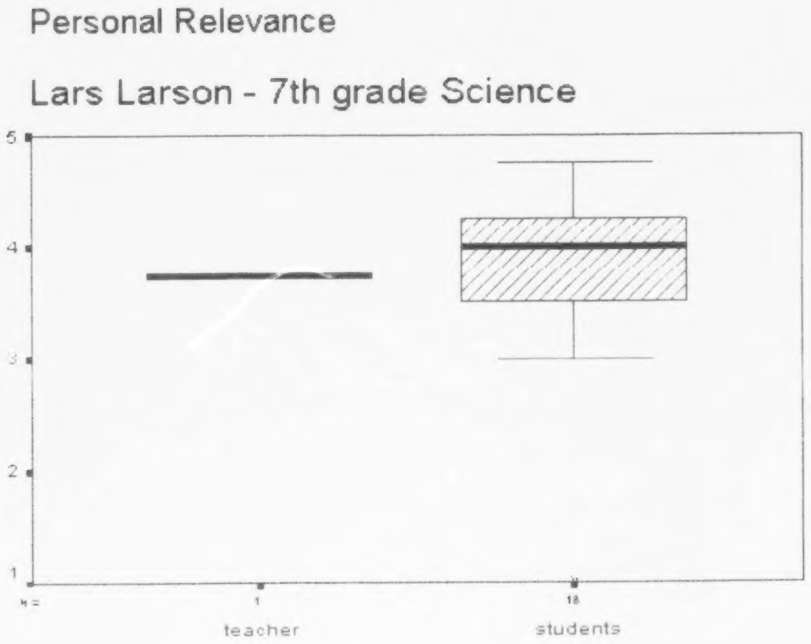
Table 2

Alignment of CLES2 (20) Scales with TRN Profile Categories

CLES Scale	TRN Profile Category
Personal Relevance	Knowledge of Content
Uncertainty	Knowledge of Content
Critical Voice	Knowledge of Students
Shared Control	Knowledge of Pedagogy
Student Negotiation	Knowledge of Pedagogy & Knowledge of Students

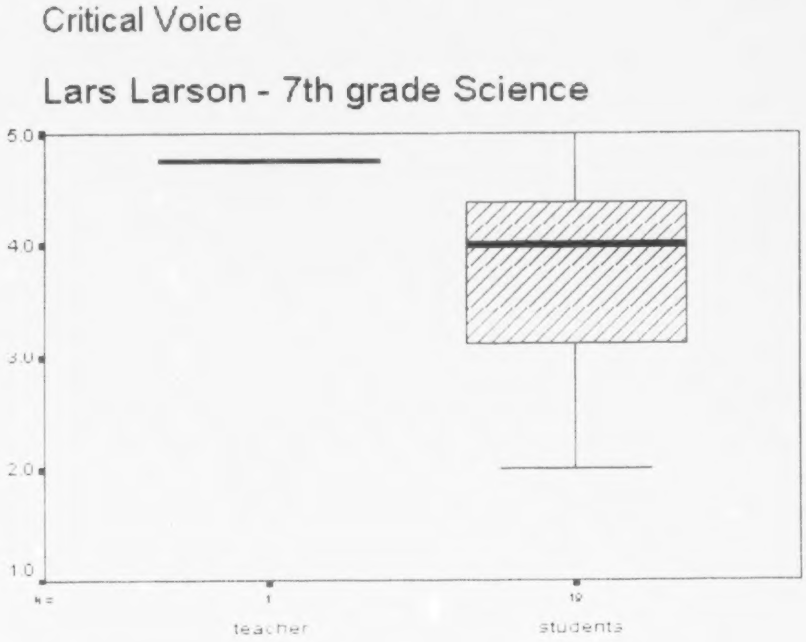
To interpret the CLES2 (20) data, those writing the profiles receive graphs showing how the teacher's perceptions compare with those of his or her students for each scale. For example, Lars Larson, a 7th grade science teacher, has perceptions of his classroom environment that for some scales fit with those of his students and for other scales are rather different. Figure 1 shows the personal relevance scale. Lars sees the relevance of the content in his classroom as being fairly high, $\underline{M} = 3.75$ on a scale of 1 to 5. His students for the most part agree with him. The students' mean ($\underline{M} = 3.81$) is essentially the same as their teacher's, and the variation is not great.

Figure 1.



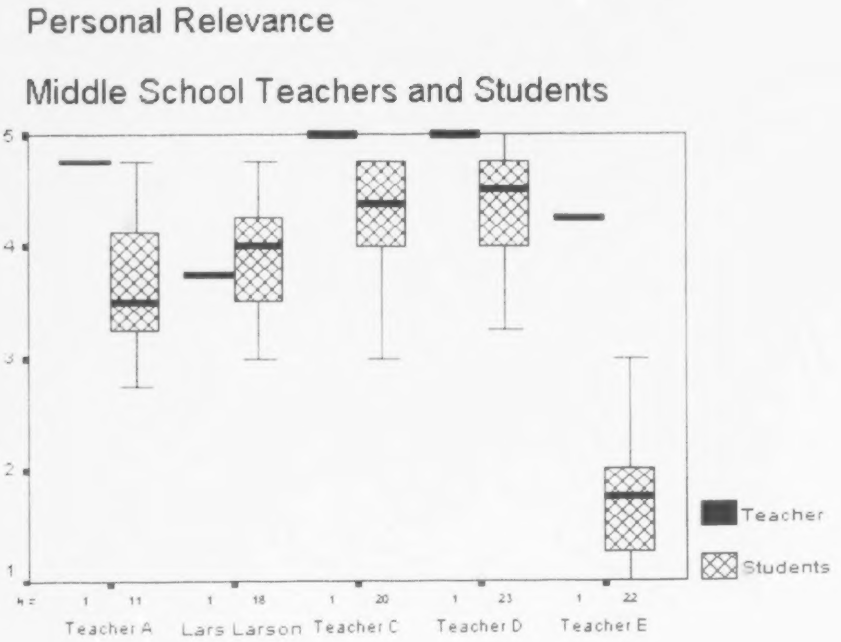
For the critical voice scale, however, the views of the Lars and of his students differ substantially. The teacher views his classroom as having a high degree of "critical voice" (M = 4.75 on a scale of 1 to 5). His students (figure 2) have a lower mean (M = 3.80) and a wide range of views. Clearly, most students do not feel as free about questioning the teacher's plans and pedagogy as the teacher thinks they do.

Figure 2.



Another way to look at this data is to compare classrooms. Figure 3 shows how this class compares with other middle school science classes for the personal relevance scale. Three of the other teachers rated it higher in their classrooms than Lars did in his, and in those cases the students were not too far below the teachers. In one case (Teacher E), though, the students emphatically disagreed with the teacher, rating personal relevance as very low.

Figure 3.



In this study, the CLES2 (20) provides important teacher and student perspectives that contribute to profiles of the teachers and their classrooms, giving us a better understanding of how our graduates are teaching.

Minnesota Science Teacher Observation Instrument

The Minnesota Science Teacher Observation Instrument (MNSTOI) is a structured observation instrument used to collect data within the classroom. The instrument organizes the observation process around the five characteristics of quality teacher preparation identified by Minnesota (Simpson and Wallace, undated). All data collection is organized in the TRN process around these same five characteristics. Focus questions direct observations within each category and these are further defined by specific prompts designed to guide the researcher. These prompts are meant to ensure that every researcher examines a teacher in as similar a manner as possible.

Origin of the instrument

The MNSTOI was its origins in three sources. The format of the instrument was taken from the Educational Testing Service's Praxis format. We use a pre-observation questionnaire, an observation and a post-observation questionnaire. We had originally investigated using the Praxis observations for the project but decided to develop our instrument due to the cost of the instrument, the intensive training required for use and the fact that it was not science specific.

The conceptual framework of the instrument was developed from Transforming Teacher Education: A Minnesota Framework for Science and Mathematics (TTE) (Simpson and Wallace, undated). This document was developed ten years ago and was developed to reflect current research, best practice and the beliefs of major Minnesota stakeholders about the knowledge and skills needed by beginning teachers of mathematics and science. The document provides standards for what beginning teachers should know and be able to do. These standards are divided into five sections, content, pedagogy, students as learners, establishing an environment for learning and developing as a teacher of science.

The third source used in the development of the document was the assessment guide developed for the (INTASC) portfolio project (Collins, 2002). This project developed a series of instruments that were designed to analyze a teacher portfolio. Included in that portfolio were teacher reflections, lesson plans, student work and videotapes of two lessons. The portfolio instruments include a series of prompts that examined teacher practice in light of the INTASC standards. Our MNSTOTI modified those prompts to better align with the TTE framework.

MNSTOI Components for Each Observation

Each teacher observation begins with examination of the teacher's demographic information. This included information about the teacher's background, school, the class being observed, course and student data. The teacher has previously competed a pre-observation questionnaire with 13 questions which includes a lesson description, including goals and a rationale that supports the teachers choices about her choice of activities, materials and assessments. Three students are selected by the teacher to represent diversity in the classroom and the teacher describes how the lesson has been modified to meet the needs of these students. Items for teacher comment are included for all five-teacher knowledge categories used in this study.

After examining the pre-questionnaire, the researcher makes a brief sketch of the classroom and begins the structured observation. At the conclusion of the observation, the teacher instructs the teacher to complete the post-observation questionnaire with 11 items and return it to the researcher within a period of one week. The post observation questionnaire allows the teacher to reflect on both her performance and that of the students. The teacher is asked to suggest if changes are needed for future lessons or for use of this lesson in another class. The teacher is also asked to comment on a need for support in terms of resources or advice to help improve the lesson

At the completion of each observation, the researcher is asked to write a summary of the lesson. This summary includes information from the lenses of the teacher through information provided in the two questionnaires and the lens of the researcher through what was observed. The report is organized around the teacher knowledge categories used in this study.

Two observations of the classroom are conducted. Both observations are selected at the convenience of the teacher and the researcher. The teacher identifies one lesson as having an inquiry focus and the second lesson is selected to represent a lesson in which a concept is being developed.

Table 3

Outline of Observational Process

Initial Visit
- Share purpose of research and overall procedures; Introduce forms; and, describe the reward process.

First observation
- Review teacher comments on demographics and pre-observation forms; Sketch classroom; complete notes of observation; and, Make arrangements to obtain post-observation form.

Lesson Report
- Use all available data to complete a summary of the lesson organized teacher knowledge categories.

Second Observation
- Repeat same process as for first observation and complete a report on the second lesson.

To provide detail for the entire observation instrument is too complex a process for this paper. Instead, what follows is information only from the section on pedagogy. This should give the reader some sense of the level of detail involved in the entire instrument.

Within the category of pedagogy, there are seven focus questions with a total of 23 prompts. Table 4 list the seven focus questions used for the observation. Four prompts are used to guide the researcher in using classroom observation to answer the question: In what kinds of science activities does the teacher engage the student? All four of the prompts associated with this question are listed in Table 5.

Table 4

Pedagogy Focus Questions

1. In what kinds of science activities does the teacher engage the student?
2. In what ways are, the activities appropriate for the instructional goals and objectives?
3. What different kinds of thinking predominate in the oral and written discourse of the classroom?
4. What is the teacher's role in fostering the oral and written discourse in the classroom?
5. In what ways does the teacher assess students' learning?
6. In what ways does the teacher communicate about the formal and informal assessments?
7. Have the students achieved the goals of learning science provided by this instructional sequence?

Table 5

Prompts associated with kinds of science activities

- Describe the variety of activities in which students engage.
- Describe the kinds of science understanding and ability the activities promote (e.g., conceptual understanding, factual recall, problem solving, application, communication)
- Describe how activities are planned (placed in instructional sequence, time allotted for tasks, use of materials, organization)
- Describe the implementation of the activities (e.g., implementation as planned, rich activities become procedural in nature, activities have potential but are used inappropriately by the teacher, activities get expanded based on student interest)

This final segment provides an example of a section of the report generated by the researcher for the question about the kinds of science activities used by the teacher to engage students. It incorporates information from the both teacher questionnaires and the observation of a lesson on genetics. Notice that the emphasis of the report is on evidence collected from the observations and questionnaire and that the researcher does not attempt to interpret the data collected at this point in time. The teacher has identified this lesson as one that develops important concepts related to genetics. This lesson had to be modified by the teacher to accommodate instruction loss of the previous days class due to snow. The researcher also had copies of the notes given that day and the genetics packet referenced by the teacher.

"The lesson observed included an introduction to a genetics unit. The purpose of the genetics lesson was to introduce the basic terms of genetics (pre-interview). The genetics class began with general announcements, an overview of instruction for the week, and a return of cell quizzes. In the weekly overview, the teacher stated computer simulations were to be used later in the week (MNSTOI). Students were provided with a packet on genetics that included genetics problems and associated questions. Notes were given on genetics information. According to the teacher, only essentials were provided on the overhead notes (3 pages), the teacher also explained and asked questions throughout the note taking process. Students and teacher worked together on Punnett Square problems from page 1 of the packet; page 2 was assigned for homework. The majority of the class focused on developing conceptual understanding of genetics with an introduction to the use of a tool (Punnett Square). The organization of the activities was appropriate. It began with an overview of the unit, an introduction to concepts and a chance to use the information from the notes in another way. (MNSTOI). The note taking section of the class was shortened to compensate for a snow day. The teacher believed the activities met the teacher's objectives for the day (post interview).

Minnesota Science Teacher Interview Instrument

The Minnesota Science Teacher Interview Instrument (MNSTII) is a structured interview instrument used to collect information from a practicing K-12 science teacher. Its fifteen questions (with their prompts) are also organized around the five characteristics of quality teacher preparation identified by Minnesota (Simpson and Wallace, undated).

Origin of the instrument

The MNSTII has it origin with the TPPI interview instrument developed by the SALISH project. The MNSTII differs from the TPPI as it asks fewer questions and its questions are aligned and limited to the five characteristics of quality teacher preparation identified by Minnesota.

Interview Procedure

The use of MNSTII is the last step in the study of a participating classroom teacher. It is important that the interview be last so that points discussed in the interview do not tip off the participating teacher to any observer or study emphasis. The average interview takes sixty to ninety minutes and is audiotaped. When interviewing elementary teachers about their science teaching, they are reminded that the interview questions asked are directed only at their science instruction. The tape is then transcribed verbatim. The tape and verbatim transcription are both used in the analysis.

Following the practice of this presentation I will focus now on the interview questions for the section on pedagogy. In the pedagogy section of the MNSTII are three questions with their respective prompts.

Table 6

Knowing Pedagogy Questions and Prompts:

What kinds of science activities do you use? Probe for:

> -This person's definition of "activity" (What counts as an activity?)
> -Ratio of engaged activities to seat work/lecture during science class
> *(Comment: For our purposes, "engaged activities" means investigation, demonstrations, projects, questions, problems, applications, and exercises in which students actively engage. "Seat work/lecture" reflects a passive role for students who are working on lower order questions, definitions, crossword puzzles, or listening to a lecture. Interviewers are asked to avoid stating these definitions to participants as that would taint their view.)*

How do you pick which activities to use? Probe for:

- Criteria used to select activities
- How they prioritize activities within the given time constraints

How do you evaluate student learning? Probe for:

- Sources of evaluations
- When evaluations are created/procured
- How teacher makes sense of results
- If/how instruction is modified in response to results

What follows are excerpts from the answers to the questions (see above) from the pedagogy section of MNSTII from the same teacher used above who taught a lesson on genetics as discussed in the MNSTOI section above. In this paragraph Lars Larson is describing the characteristics of the activities used in his seventh grade science classroom:

> "Punnet squares, percentages and ratios. That's some big math concepts going on…We're talking about these big gigantic words: zygo's, hetero's, homo's, zygo's'. So they have to know language, they have to know math, they have to go over their reading abilities [to read the text]. I had them coloring and drawing in my class. These are art skills…In science class you use a whole bunch of different stuff; you're thrown in a whole bunch of different realms."

When questioned about how Lars evaluates learning, he said:

> " I use scantron/multiple choice tests, worksheets, and practical lab type tests." When probed for an example of a practical lab type test he reported, "identification of birds from a slide show."

Our set of three instruments described above is designed to provide "triangulation" of information on classroom instruction. In particular, the interview instrument can be used to corroborate patterns noted during the classroom observations. These two instruments complement each other to provide a clearer picture of a teacher's practices, knowledge, and beliefs about science teaching when the researcher summarizes data and observations into a written profile. Here is an excerpt from the "Knowing Pedagogy" section of Lars Larson's profile that demonstrates this relationship:

> Appropriate Activities
> He knows that his students are "not really that interested yet in stuff out of a text book. So it [subject matter] needs to be very right there, they can see it." He continues, "They haven't got to the point where just by reading it they can get interested in it." (MnSTII) Consequently, he chooses instructional materials that are within the grasp and of interest to junior high students, such as an article entitled "Insect Munchies" (MnSTOI – insects), videos from the "Eye Witness" series (MnSTOI – insects, post-observation), an a computer simulation program about genetics (MnSTOI – genetics, post-observation).

Some types of information can only be gained through the interview instrument, such as the section on "Developing as a Teacher" as found in the MNSTII. It is not addressed in the CLES 2(20) and is not often observed in the MNSTOI. For the section "Developing as a Teacher" MNSTII asks the following questions:

Table 7

Developing as a Teacher Questions and Prompts:

Have you participated in professional development beyond your university preparation? Probe for:

- meetings, organizations, books, workshops, conferences, mentors

What resources do you use in your teaching and planning that come from outside your classroom?

- school, district, community, state, national

I'm going to ask you to make a pie chart that shows the relative pieces that have contributed thus far to your preparation as a teacher.

- undergraduate courses, graduate courses, books, field experiences, classroom experience, anything else you can think of
- influence of various pieces on their professional growth.

(Comment: It might help to ask the participant to make a list first and then decide the relative impact of each piece.)

Analysis

A teacher profile is developed to summarize teacher data collected from the four instruments described above. Each profile used a similar format, providing descriptions of the participants' teaching in five categories (I-Knowing Science Content, II-Knowing Pedagogy, III-Knowing Students, IV-Establishing a Learning Environment, V-Professional Development) that correspond to our research questions. Also included was a section that described key demographic information about the participants and pertinent contextual elements such as school settings, course information, and community type. A meta-analysis is then completed on sets of teacher profiles. Two categories, elementary science and secondary science, are used for analysis. All profiles within a subgroup are analyzed by a single researcher with knowledge and expertise in the area corresponding to the descriptor for each subgroup. Profile analyses were reviewed and confirmed by two additional reviewers for each set of profiles. A more complete description of this analysis including samples of profile analyses can be found in the second presentation summary, Getting to the Fourth Year: Preliminary Findings Regarding the Practice of MN Beginning K-12 Science Teachers, found elsewhere in these proceedings.

Future Directions

We have currently completed three years of data collection. This year we will add several new teachers to the project and follow others for a second or third year. New participants and follow-up studies continue to raise new questions about teacher practice. At this point, we are satisfied with the instruments and our plan for data analysis

We believe more work is needed with TRN participants to assure that we have common meaning for terms used in the study. We have learned many lessons about the process of collaborative research and feel it can provide important findings about beginning teachers to the science education community as a whole. Further study is warranted before refined assertions will emerge from the data. Nonetheless, the current results of this study have spawned a wealth of further research questions rich in potential and more focused in scope. We believe that the emerging research will mature into insightful assertions that can help us pursue excellence in Minnesota science teacher preparation.

Authors Notes:

1. Teacher Research Network

These are the researchers who have contributed to the development of the instruments and/or participated in the collection of the data through the 2000-2001-research year.
Some researchers have moved to other institutions since their participation in TRN.
Cyndy Crist, SciMath^{MN} higher education project director; George Davis,
Minnesota State University Moorhead and Patricia R. Simpson, St. Cloud
State University; TRN co-directors. Researchers are: John Bauman, College of St.Scholastica; David Cline, Saginaw Valley State University; Alice Mae Guckin, College of St. Scholastica; Lynn Hartshorn, University of St. Thomas; Jean Hoff, St. Cloud State University;; Michele Koomen, Gustavus Adolphus College; Carmen Latterell, University of Minnesota Duluth; Robert McClure, St. Mary's University; Jeff Pribyl, Minnesota State University-Mankato; Lon Richardson, Southwest State University; Teresa Shume, Minnesota State University Moorhead; Chery Takkunen, College of St. Scholastica; Tom Tommet, University of St. Thomas; Dorrie Tonnis, West Bend, WI; Kay Wohlhuter, University of Minnesota Duluth.

2. To obtain set of study instruments and protocols send a request on institutional stationary to: Dr. George R. Davis, Regional Science Center, Minnesota State University Moorhead, 1104 7th Avenue South, Moorhead, MN 56560. Questions can be sent to George Davis at davisg@mnstate.edu.

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IMPACTS OF CONTEXTUAL AND EXPLICIT INSTRUCTION ON PRESERVICE ELEMENTARY TEACHERS' UNDERSTANDINGS OF THE NATURE OF SCIENCE

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Karen Irving, University of Virginia
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Science educators have identified the development of accurate understandings of the nature of science as an instructional goal for nearly a century (Lederman, 1992). Despite the longevity of this instructional goal, research has consistently shown that K-16 students do not attain desired understandings (Duschl, 1990; Lederman, 1992, among others). One explanation for students' lack of success in learning current conceptions of the nature of science in K-12 classrooms is that the vast majority of elementary and secondary teachers rarely address this topic explicitly in their science instruction. Much of this failure is due to the lack of emphasis on the nature of science in the science courses of many teacher preparation programs. However, even programs emphasizing the nature of science as a theme have met with limited success in facilitating preservice teachers' abilities to understand and teach this elusive construct (Abd-El-Khalick, Bell, & Lederman, 1998; Akindehin, 1988; Author, 2000; Haukoos & Penick, 1983, 1985; Olstad, 1969; Scharmann & Harris, 1992). One possible explanation for the insufficiency of these programs is the uncontextualized manner in which they address the nature of science. With science instructors unlikely to focus on the nature of science in content courses, the nature of science lessons are generally relegated to the methods courses, where they are typically presented out of context as an add-on to the science curriculum (Driver, Leach, Millar, & Scott, 1996). When addressed in this manner, preservice teachers may see the nature of science as supplemental, rather than integral to their science instruction.

Current science and technology based issues such as global warming present the "messiness" of science-in-the-making and bring students into direct contact with the values, assumptions, and concepts embodying the nature of science. Furthermore, science and technology based issues situate lessons about science in the context of learning relevant science content. In many cases, these issues can be presented as subunits within a typical science methods course, eliminating the often-difficult task of finding science professors willing and able to tackle the nature of science in their content courses. Thus, many have argued that science and technology-based issues provide an ideal context for enhancing students' and teachers' understandings of the nature of science (Bentley & Fleury, 1998; Collins & Pinch 1998; Spector, Strong, & La Porta, 1998).

The Nature of Science

Although there is some disagreement regarding the specifics of the nature of science, there is an acceptable level of generality regarding the nature of science upon which the majority of experts agree and which is relevant and accessible to K-12 students (Lederman & Abd-El-Khalick, 1998; Smith, Lederman, Bell, McComas, & Clough, 1997). Included are the concepts that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory-laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), and socially and culturally embedded. Two additional aspects focus on the distinctions between observation and inference and the role and distinction of scientific theories and laws. This characterization of the nature of science is supported by current science education reform documents (American Association for the Advancement of Science, 1993; National Research Council, 1996), and it provided a conceptual framework in the present investigation. For a more detailed description and justification of this characterization, see Lederman, Abd-El-Khalick, Bell, Schwartz, & Akerson (2001).

Method

Purposes

The purposes of this study were to assess (a) the influence of instruction on a controversial science and technology based issue (global climate change and global warming, or GCC/GW) on elementary preservice teachers' understandings of the nature of science, and (b) the relative effectiveness of an explicit approach versus an implicit approach to the nature of science instruction. To this end, a matrix of the nature of science and GCC/GW instructional treatments were employed over a period of four semesters (Table 1).

Table 1

Treatments by Semester

Semester	Treatment	# of Participants
Spring 2000	GCC/GW, explicit NOS	15
Fall 2000	No GCC/GW, implicit NOS	20
Spring 2001	No GCC/GW, explicit NOS	18
Fall 2001	GCC/GW, implicit NOS	22

Participants

The study involved all elementary preservice teachers enrolled in a required three-credit elementary science methods course at a major mid-Atlantic university. In total, the participants numbered 75 (70 females, 5 males), with ages ranging from 21 to 38 years. Most were fourth-year students enrolled in a 5-year BA/MT program. The majority (89%) were liberal arts majors, with the other 11% majoring in science or mathematics. The MT program has a rigorous admissions policy focusing on GPA, GRE scores, and prior experience working with children. The consistent application of the MT admission criteria facilitated homogeneity of aptitude and achievement across treatment groups.

The Intervention

The controversial science issue selected for inclusion in the elementary science methods course was global climate change and global warming (GCC/GW). In the semesters when GCC/GW was taught, approximately 7 hours of class time were devoted to this instruction. Assignments included readings and discussion from popular periodicals and climatology literature, as well as hands-on inquiry activities related to GCC/GW (see Matkins & Bell, 2001 for a description of these activities). Additionally, environmental science faculty who were specialists in climatology met twice with the preservice teachers in small group settings to discuss current research findings and applications in the K-8 classroom.

Preservice teachers who received explicit nature of science instruction participated in a set of five inquiry-based activities taken from Lederman & Abd-El-Khalick (1998) and Lederman, Abd-El-Khalick, and Bell (2000) and a discussion of one reading assignment (Springston, 1997) selected to teach the seven target aspects of the nature of science. The preservice teachers participated in class discussions focusing on relevant nature of science aspects following each activity. Furthermore, in the nature of science with GCC/GW treatment group, the instructor encouraged the preservice teachers to relate characteristics of the nature of science to GCC/GW concepts as they were being taught.

Preservice teachers in the implicit nature of science instruction groups participated in none of the explicit nature of science activities in order to limit the potential source of changes in their nature of science understandings to implicit sources (either the GCC/GW instruction and/or the inquiry-based methodology promoted by the elementary science methods course).

Data Collection

Data sources included pre- and post-questionnaires, interviews, relevant course assignments, and electronic journal entries. The nine-item open-ended questionnaire used to assess understandings of key elements of the nature of science and GCC/GW was based on the Views of Nature of Science questionnaire (Lederman et al., 2001). Five items focused on the previously mentioned aspects of the nature of science and four items related to GCC/GW. Following each administration of the questionnaire, six participants were interviewed to help establish validity of the questionnaire responses. Preservice teachers were purposefully selected for interviews to produce a stratified sample based on the available range of science backgrounds (from few to many secondary- and college-level science courses). During the audiotaped interviews, participants were asked to explain and elaborate on their responses to the questionnaires.

Data Analysis

In analyzing the data, the researchers have sought to provide rich descriptions of the beliefs of a limited number of participants based upon qualitative data, rather than less detailed treatment of a much larger sample. The descriptions will include excerpts from the preservice teachers' assignments, journal entries, questionnaire responses, and interview transcripts. It should also be noted that due to the participation of all students in the four semesters of the investigation and the inability to randomly select from among all preservice elementary teachers, it made most sense to treat the participants as the population, rather than a sample. What this approach loses in terms of generalizability, it gains in authenticity (generalization from such a small, nonrandom sample makes little sense). Thus, this investigation may be seen as an initial attempt to frame the issues and as a foundation for future research.

The various data were first analyzed individually using Bogdan and Biklen's (1992) model of analytical induction and then together in order to test the validity of developing assertions. In this approach, working hypotheses to describe/explain the participants' views were continually formed and then tested against subsequent data. The ultimate goal was to develop generalized profiles for the preservice teachers' nature of science and GCC/GW understandings derived from systematic examination and re-examination of the available data. The variety of data sources permitted the triangulation of data and supported the validity of the profiles of each apprentice's understandings and apprenticeship experience. Finally, participants' profiles were compared to assess changes in the nature of science and GCC/GW understandings, and overall gains were compared among all treatment groups to assess the relative effectiveness of the four instructional approaches. Since two researchers analyzed the data, it was necessary to establish inter-rater agreement prior to the analysis of the entire data set. The researchers accomplished this through systematic comparison of separate analyses of three randomly selected data sets, with the end result of 90% agreement.

Results and Discussion

Results of the analyses of the preservice elementary teachers' responses to the questionnaire and follow-up interviews indicated significant pre- to posttest differences in their views of the nature of science and global climate change when those topics were explicitly addressed in the class. Overall, in the semesters where nature of science was taught explicitly, the posttest responses reflected current understandings at a substantially higher rate than those of the pretest (Table 2). Each data table is followed by a summary of pre and posttest responses and by representative quotations. The coding system used in the following sections delineates whether specified data were collected prior to (Pre-) or after (Post-) and to identify individual participants (1 to 22). The concluding component of the coding system is the semester in which the individual was in the class (Spring/Fall, 2000/2001).

The Nature of Science

Pre-Instruction Views of the Nature of Science

The preservice teachers' pre-instruction responses reflected common misconceptions about the nature of science. For example, the majority viewed scientific knowledge as absolute truth. All participants believed that theories become scientific laws when proven true, and most were unable to explicate roles for imagination, creativity, or social influences in the development of scientific knowledge (see Table 2).

The Empirical Nature of Scientific Knowledge

The level of understanding of the empirical nature of science was consistently low across all semesters. Most of the participants were familiar with the use of evidence in science, and referred to scientists' use of observations and data. However, most also indicated that data and observations are the sole source of evidence, and that scientists use data and observations to *prove* their theories and conjectures. The roles of creative thought and the development of inferences in the establishment of scientific knowledge were not mentioned by most participants

> A scientific theory is an idea that has been tested and scientists are still testing to prove the theory as true.... A scientific law is a theory that has been tested and proven. (Pre-1, Spring 2000)

> I think that theories sometimes change. Using new technology scientists are able to find out more and more information regarding scientific theories. (Pre-6, Spring 2001).

Table 2

Percentage of Participants with Desired Views of Targeted Nature of Science Aspects

NOS Aspect	Spring 2000 Explicit GCC Explicit NOS (*n* = 15)		FALL 2000 Implicit GCC Implicit NOS (*n* = 20)		Spring 2001 Implicit GCC Explicit NOS (*n* = 18)		FALL 2001 Explicit GCC Implicit NOS (*n* = 22)	
	Pre%	Post%	Pre%	Post%	Pre%	Post%	Pre%	Post%
Empirical nature of scientific knowledge	27	73	0	0	17	68	9	9
Tentative nature of scientific knowledge	0	60	0	5	6	56	5	9
Role of creativity	0	67	0	0	6	67	0	5
Subjective nature of scientific knowledge	20	80	0	5	17	67	32	23
Social & cultural influences	0	27	0	0	0	0	0	0
Observation vs. inference	27	67	0	0	6	56	14	14
Theories vs. law	0	80	0	0	0	78	0	0

The Tentative Nature of Scientific Knowledge

Consistent with the belief that a goal of scientists is to prove their ideas, participants viewed theories as weakly supported ideas that were easily and often revised. This misconception about the tentativeness of science as it related to scientific theories was common across semesters. In addition, participants consistently discussed scientific laws as aspects of scientific knowledge that were proven. Thus, the absolutist beliefs of the participants at the beginning of each semester were in contradiction to the common tenet in the scientific community of the tentativeness of scientific knowledge.

> Scientific theory has not stood the test of time or cannot be proven correct 100% of the time, such as the theory of evolution. Laws of science cannot be broken. (Pre-10, Spring 2001)
>
> A great example of [theory change] is the always-baffling unanswered question of how to lose weight. At least hundreds, if not thousands, of theories exist on this topic, many of which contradict one another and confuse the public. (Pre-2, Spring 2000)

The majority saw scientific laws as proven beyond a shadow of doubt. For these preservice teachers, scientific laws, along with facts and observations, constituted absolute knowledge that would never change. These participants also expressed the misconception of a hierarchical relationship between scientific theories and laws.

> A law is a theory that has been proven beyond a reasonable doubt. (Pre-22, Fall 2001)
>
> A scientific theory cannot necessarily be proven, whereas a law is believed to be a constant, accurate explanation of something in the science world that has been tested and re-tested. A theory is usually the first step in constructing, or formulating, a law. (Pre-9, Spring 2000)

Most participants linked the tentativeness of scientific theories to the empirical nature of science. In fact, the collection of new data and the accumulation of counter evidence were typically cited as the sole source of change. None of the participants mentioned the possibility that scientific theories could change due to new insight or new ways of looking at existing data.

The Role of Creativity in Constructing Scientific Knowledge

Although most participants expressed the belief that science involved creativity, particularly in "designing experiments" and to "create ideas to be tested", no one talked about the creativity of data interpretation. Several participants cited the "scientific method" as the regimen through which science progresses, a view that is at odds with science as a creative endeavor.

Prior to instruction, most of these preservice teachers viewed creativity as playing a role only before the real science (i.e., scientific method) is applied.

> Science and art are similar because in both genres you have to be creative and willing to experiment. Scientists have to create ideas to be tested while artists create how they want to portray an idea. Both fields follow methods, need materials, and experiment. (Pre-2, Spring 2001)

> Science has a method, but it is the scientists who expand this method, who work outside of the box, that are considered brilliant and ingenious scientists. (Pre-14, Spring 2000)

The Subjective Nature of Scientific Knowledge

The preservice teachers described a degree of subjectivity as inherent to the construction of scientific knowledge. Most participants spoke of subjectivity only in a general way, such as differences in "data interpretation": "There can be different interpretations of the data based on their knowledge." (Pre-22, Fall 2001). A few of the participants' pre-instructional responses described subjectivity in the negative sense that "…sometimes people 'see' simply what they want to believe" (Pre-6, Spring 2000).

Cultural Influences on Scientific Knowledge

None of the participants made any reference to cultural influences on the scientific enterprise in their pre-instructional responses to the questionnaire and follow-up interviews.

Post-Instruction Views of the Nature of Science

Substantial changes in participants' nature of science views were realized only in the post-instruction responses of the participants in the two explicit nature of science treatment groups (Table 2). In general, these responses reflected less commitment to absolute views of science and greater understandings of human factors contributing to the tentative nature of scientific knowledge. These results add further support to the growing body of literature supporting an explicit approach to the nature of science instruction (Akerson, Abd-El-Khalick, Lederman, 2000; Bell, Blair, Lederman, & Crawford, 1999; Shapiro, 1996).

The Empirical Nature of Scientific Knowledge

In the semesters that involved explicit instruction in the nature of science, the participants' post-instructional views differed in that a high percentage (73% and 68%) realized that scientists often go beyond the observable when constructing scientific ideas and theories.

> Different scientists look at the same topic in different lights drawing from their own theories, backgrounds, and research. While they have the same data, these factors lead them in different directions and approaches to the topic. (Post-12, Spring 2000)
>
> Every scientist comes to his work with a different set of experiences and pre-conceived notions. Just as two people can look at the same drawing/read the same poem and see/hear different things, so too can two scientists deduce different information. (Post-6, Spring 2001)

Whereas references to "proving" scientific ideas as "true" were common in the pre-instruction responses, the same ideas were largely absent from the post-instructional responses in the groups who received explicit instruction in nature of science. In the groups who received no explicit nature of science instruction, there was no change in the very small percentage of students who recognized the usefulness of various perspectives in the development of scientific knowledge.

The Tentative Nature of Scientific Knowledge

In the groups that received explicit nature of science instruction, post-instructional responses indicated important shifts in the participants' largely absolute views of scientific knowledge. While all participants continued to express the belief that theories change because of new evidence, several also described theory change as a result of new ways of looking at existing evidence.

> I think theories change….The theories about dinosaur extinction have changed because of new evidence and a new perspective on data. (Post-1, Spring 2000)

> Since theories are founded on interpretations of observations, different scientists may propose different theories despite potential use of the same set of data. (Post-11, Spring 2000)

All of the participants who received explicit nature of science instruction also spoke of the explanatory function of theories, something that was entirely lacking in their pre-instructional responses. In fact, in a majority of the post-instructional responses, participants contrasted theories and laws by their function, rather than level of "proof." Some referred specifically to nature of science activities in which they participated in their class.

> A scientific theory explains why something is happening. A scientific law is a summary of observations. It is a generalization ... it explains why something is happening. In the tube experiment, we made a law that said that no matter which string we pull, the longer one goes in. This is a summary of all our observations. (Post-18, Spring 2001)

> A scientific theory is an explanation of why something happens. A law is a summary of observations – it is a generalization about a phenomenon that is explained by a theory. (Post-2, Spring 2001)

Post-instructional responses in the two explicit nature of science groups also tended to contrast theories and laws by the types of knowledge from which they are derived. The participants clearly saw theories as inferential in nature and scientific laws as generalizations. This contrasted markedly with their pre-instruction misconception that laws are of the same type of knowledge and are, in fact, derived from theories.

In the two groups who received no explicit nature of science instruction there was no change in the responses about the tentativeness of science in the post-instruction data set.

The Role of Creativity in Science

In both semesters in which explicit nature of science instruction was employed, about 67% of the participants expressed adequate post-instructional views of the role of imagination and creativity in the generation of scientific knowledge. According to the participants in these two semesters of the course, creativity permeates the scientific process in both the design of experiments and in the interpretation of data. Most agreed that "creativity drives both scientists and artists" (Post-2, Spring 2000). The change in participants' views was further emphasized by their rejection of the conception of a single scientific method. Contrary to their prior beliefs, they allowed for many methods and creative approaches to the process of generating scientific knowledge.

> Not everything can follow the scientific method—like, if you're trying to find out about dinosaurs….I don't think that every time someone is going to state a hypothesis before they discover something. (Post-1, Spring 2000)

In the groups that received no explicit nature of science instruction, the percentage of students who expressed understanding of the creative processes in science was consistently negligible.

The Subjective Nature of Scientific Knowledge

The view that science is completely rational and objective was rejected by 80% and 67% of the participants in the explicit nature of science groups, in their responses to Item 5 of the posttest. Rather, they described how scientists' backgrounds, personal views, and biases toward the data potentially played a role in their interpretation of the data. Contrary to their pre-instructional responses, none of the participants cast subjectivity in a totally negative light.

> It is possible that different people make different inferences from the same data and observations. (Post-17, Spring 2001)

Different conclusions are the result of different interpretations of data. Scientists draw varying inferences based on unique personal experiences, backgrounds, and systems of thought and belief. Every individual is the product of a unique set of life experiences, program of study, and mindset. All of these factors affect how a researcher interprets a given set of data. (Post-11, Spring 2000)

Students who did not receive explicit nature of science instruction persisted in their general statements about why scientists might differ in their beliefs. None cited different interpretations of the data as a reason, and several continued to characterize differences in science as the result of personal bias and prejudice on the part of scientists. Even the group that received explicit GCC/GW instruction showed no gains in understanding the role of inference, interpretation, and theory development in science.

Cultural Influences on Scientific Knowledge

In contrast to the pre-instructional responses, in which the participants made no reference to cultural influences, 4 of the 15 participants (27%) in the group receiving BOTH nature of science and GCC/GW instruction described how cultural influences could affect the scientific enterprise and the knowledge it constructs. Three of these references to cultural influences described how the culture at large could affect what science is done and how it is received.

> [Without teaching theories] we would not see, for example, that the Copernican model that the earth revolved around the sun was widely unaccepted during his time because it rejected the Christian idea that the Earth is at the center of the universe and everything revolved around it. (Post-12, Spring 2000)

In the other three groups there was no gain in understanding the impact of the culture upon the scientific enterprise. This was the only aspect of NOS in which the second NOS group, the one which received no GCC/GW instruction, made no gains.

Global Climate Change/Global Warming

Pre-Instruction Views of Global Climate Change and the Nature of Science

In all semesters of the project, a large majority of the preservice teachers held pre-instruction misconceptions about GCC/GW. These included beliefs that the greenhouse effect is both unnatural and (always) harmful, that scientists as a group believe the same thing about GCC/GW, and that the greenhouse effect is either a scientific theory, because it is unproven, or a scientific law because it is proven.

In the pre-instruction questionnaires and interviews in all semesters, student responses ranged from statements about GCC/GW that contained multiple misconceptions to responses that used some correct descriptions and terminology. The ideas found in the following examples were commonly expressed in all semesters in the pre-instruction responses. Many students believed that the ozone hole was the primary causal factor in the greenhouse effect, that the greenhouse effect and global warming were synonymous, and that the greenhouse effect worked by trapping heat or gasses in the atmosphere.

> It [the greenhouse effect] is caused by a hole in the ozone layer which allows stronger sun rays in. The heat of the sun is slowly heating the temperature of the earth causing the polar caps to begin melting. This increases the amount of water in the ocean and leads to erosion on the shores and loss of land. (Pre-2, Spring 2000)

> The greenhouse effect is the gradual loss of the protective ozone layer due primarily to the release of certain man-made gasses. The loss of the filter is allowing more of the sun's rays to pass through the atmosphere causing a general warming of the Earth's surface. (Pre-2, Fall 2001)

In a few instances, students expressed correct understandings of the greenhouse effect and its mechanisms. Even these students expressed other misconceptions, such as characterizing the effect as a trapping of energy in the atmosphere, listing isotopes as greenhouse gases (C_{14}), naming gases that did not occur naturally prior to the 20th century (CFC's, first synthesized in

Table 3

Percentage of Participants with Desired Views of Targeted GCC/GW Aspects

Response Categories	Spring 2000 Explicit GCC Explicit NOS (*n* = 15)		FALL 2000 Implicit GCC Implicit NOS (*n* = 20)		Spring 2001 Implicit GCC Explicit NOS (*n* = 18)		FALL 2001 Explicit GCC Implicit NOS (*n* = 22)	
	Pre%	Post%	Pre%	Post%	Pre%	Post%	Pre%	Post%
Greenhouse effect (GE) is natural & mostly beneficial	26	67	15	30	6	6	5	73
Correct understanding of theory or law, connected with greenhouse effect	7	73	10	5	17	67	0	0
Scientists are characterized as individuals	40	73	35	45	22	50	27	27
Support for government energy policies	73	100	80	85	61	67	82	68
Informed conditional support for government energy policies.	0	67	5	5	0	0	0	5

1928), and failing to distinguish between particles and gases. Even the most correct descriptions were not correct to a level that one could reasonably expect any of the respondents to accurately teach the concepts to children. The following excerpts from student responses were the most correct pre-instruction responses from two class sets.

> Certain particles, CFCs, C_{14}, and others form a blanket in the stratosphere that "insulates" the earth—keeps the earth warm by keeping heat emitted from the sun around the earth. (Pre-1, Spring 2000)

> Radiation from the sun enters into the earth's atmosphere and it is both absorbed by the earth and reflected by it. Part of the light and heat energy that is reflected gets trapped by the atmosphere and warms the earth.(Pre-15, Spring 2001)

Across semesters, participants' pre-instruction explanations about whether the greenhouse effect is a theory or a law reflected conventional understandings about theories as unproven conjecture and laws as proven. This was consistent across groups.

> If it were a law, it is probable that results/consequences of the phenomena would have to have been observed and recorded a number of times (it would become provable and a fixed phenomena). (Pre-9, Spring 2000).
>
> Theory. Since there is a difference of opinion on why the earth is warming, the greenhouse effect is only a theory. If someone could prove that the greenhouse effect explains the earth's warming 100% of the time, then it could be a law. (Pre-12, Fall 2000)

Another characteristic student belief was the uniformity of opinion about global warming in the scientific community. Most responses contained references to scientists as a single-minded group whose beliefs were expressed as one unit. This response corresponded to their pre-instruction beliefs about the subjectivity of science, and was consistent with their absolutist views of science.

> Scientists are certain that there is a hole in the ozone layer that continues to expand. Scientists are uncertain about the rate at which it is expanding, nor do scientists know for sure how grave the danger of increasing temperatures is. They only know that the Earth in general is warming up. (Pre-5, Spring 2001)
>
> Scientists are about 75% sure that the Earth is warming at a dangerous rate. They are trying to increase awareness about pollution and the depletion of the ozone to slow the warming of the Earth. (Pre-9, Fall 2001)

Consistent with the responses of the majority of the participants each semester that scientists were in agreement about global warming, over 60% each semester indicated willingness to support the development of alternative energy sources even if the actions taken raised their taxes or cost them in other ways. Pre-instruction data showed only one example in all semesters of application of knowledge of the nature of science and/or of GCC/GW in response to this question.

> Yes. I'm pretty convinced that emission reduction would perhaps slow down, if anything, this perceived effect. The problem is expense, of course, but I, personally, would support such a program. (Pre-10, Fall 2000)

The previous response contrasted with the prevalent sentiment expressed. Most students supported taxation for the proposed government program with reasoning that lacked critical consideration of the nature of science or the issue of global warming.

> Yes - anything to help save our Earth would be worth it. Eventually, they would hopefully be able to get the prices down. (Pre-18, Spring 2001)

> Yes!!! (Pre-17, Fall 2001)

Post-Instruction Views of Global Climate Change and the Nature of Science

As expected, only in the explicit GCC/GW groups did participants demonstrate substantial post-instruction gains in GCC/GW understandings. Though not every participant in the explicit GCC/GW groups moved to correct and complete understandings, a large portion of each class did (Table 3). Also, most participants were willing to support government action to encourage the use of alternative energy sources. The following sections highlight the changes in participant understandings of global climate change and the nature of science as it intersected with the study of global climate change.

At the end of the explicit GCC/GW semesters many more students held the correct understanding of the greenhouse effect, in contrast to very few at the beginning of the semester. The understandings expressed in their posttest questionnaires were generally more thorough and showed a deeper understanding of the processes involved in the greenhouse effect. Some respondents made a direct connection between the nature of models and the greenhouse effect as a model. Given that most participants were confused about the greenhouse effect at the beginning of the study, the thoroughness and clarity of posttest responses is especially notable.

> The greenhouse effect is a proposed explanation for increased Earth temperatures. It is not the same as "global warming," and often receives a negative connotation. The greenhouse effect is a model, much like a real greenhouse, that reflects gases held to the Earth by gravity that in turn insulates the earth's surface because of a loss of energy – we probably couldn't live on earth without some degree of greenhouse effect. (Post-9, Spring 2000)
>
> It is the net warming of the earth because some of the sun's energy is absorbed by the earth and then re-emitted and absorbed in the atmosphere. But some of the sun's energy escapes back into space. It does not cause "global warming," it is actually the phenomenon that allows the earth to be at this temperature. Otherwise temperatures would drop below 0 . (Post-20, Fall 2001).

Only in the explicit NOS instruction semesters did students' post-instruction responses indicate that a majority of the students understood that scientists are individuals and have various opinions about GCC/GW. In the semester where students received explicit instruction in both GCC/GW and NOS, 80% of the students in the class learned that scientists differ in their ideas about whether or not global warming is happening at a dangerous rate, as compared to 53% on the pretest. In the posttest responses, participants expressed an understanding of the function of inference in the development of scientists' ideas about global warming.

> Some scientists are certain that the Earth is warming at a dangerous rate. Some scientists are certain that the Earth is cooling, while others are certain it is all part of a cycle. They are all inferring different things based on the same data. (Post-4, Spring 2000)

In the other semester that included explicit NOS instruction, responses reflecting the individuality of scientists more than doubled in pre- to post- responses. For example, "I would say some scientists are certain while others aren't. " (Post-5, Spring 2001). Despite explicit reading assignments and meetings with research scientists, the explicit GCC/GW groups that did not receive explicit NOS instruction showed very little gain in understanding of the subjectivity of science as exemplified in the debate in the scientific community over global warming.

> I do not think they are very certain. They are just trying to follow the calculations that they have figured out. (Post-8, Fall 2001)

Prior to instruction, most participants in all semesters of the project based their choice of "theory" or "law" to characterize the greenhouse effect upon whether or not they believed the greenhouse effect was proven or not. Participation in the science methods course without NOS instruction did not result in gains in correct understandings of scientific theories and laws. GCC/GW instruction did not lead to gains in this area of nature of science understanding. In contrast, after instruction in the two explicit NOS semesters, about 70% of the participants responded to the question with correct explanations about theories and laws, and all 70% referred to the nature of the reasoning as the justification for their answer. Furthermore, they used the science process nomenclature of observation and inference, as they had been taught in the course, to clarify their reasoning.

> The greenhouse effect is a law—if it is described as the reflective effect of the atmospheric gases on radiant energy. If, however, it is described as being the effect of changes in atmospheric composition on global climate change, it is a theory. Laws are based on strict observations while theories are founded on inferences, which involve the interpretation of observations. (Post-11, Spring 2000)

> If it's based on observations – such as records of relative amounts of gas in a sample of the atmosphere – it's a law. If it's based on inferences – such as an explanation about why the Earth's temperature is rising – it's a theory. I think it's probably a theory because it's a possible explanation of why temperatures are rising. (Post-13, Spring 2001)

With the exception of one semester group, there was no notable change across semesters in the willingness to commit to paying for a government program to develop alternative energy courses. The group that received explicit NOS and GCC/GW instruction was the only group to show an overall shift to the use of explanations about their choices consistent with knowledge of NOS and GCC/GW (Table 3). In addition, this was the only semester in which many students explained their willingness in a manner that showed both their understanding of the GCC/GW issue and of the nature of science.

> If consensus within a majority of the scientific community were reached about the earth warming at a potentially detrimental rate, yes I would support the move to more costly alternative energy sources. (Post-1, Spring 2000.)

Even without GCC/GW instruction, the group receiving explicit NOS instruction developed better understandings of theories and laws and appeared able to apply these understandings to the topic of GCC/GW (Table 3). However, these participants' responses to the GCC/GW questions on the post-questionnaires showed no improvements in the application of the NOS topic to understandings of other NOS aspects, such as viewing scientists as individuals.

Discussion

Preservice elementary teachers in these groups made substantial gains in understandings of the NOS when instructed explicitly in aspects of NOS in conjunction with instruction in a controversial science issue, GCC/GW. These participants also made substantial gains in NOS with explicit NOS instruction and *no* instruction in GCC/GW. Explicit instruction in NOS appears to benefit student understandings of NOS whether or not it is combined with a controversial science topic, though the effect was greater when NOS and GCC/GW were both taught explicitly. Likewise, when no explicit instruction in NOS occurred, no gains were seen in NOS understandings.

Interestingly, most of the participants, all semesters, *believed* they had learned about the nature of science whether or not the topic was addressed explicitly in the methods course. This belief is contrary to the data for the implicit nature of science groups, whose understandings showed little change from pre- to posttest administrations of the questionnaire. However, given their responses to specific probing during the interviews, it appears that these preservice teachers conflated nature of science with science process skills, a topic that was addressed extensively in their methods course. This conflation has been reported in previous studies involving preservice teachers (Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 2000), and serves as a reminder that it is easy for methods students to confuse the method with the message, especially when an implicit approach is used.

The only gain in the explicit global climate change/implicit nature of science group was in the understandings about the definition of the greenhouse effect. Also, in the explicit NOS groups, gains were seen in the ability to connect the correct meaning of scientific laws and theories to the greenhouse effect, regardless of GCC/GW instruction. Therefore, it appears that in-depth, student-centered coverage of a controversial issue is not enough to improve participants' views of NOS. However, accompanying NOS instruction with investigations of a real-world topic that illustrates the NOS aspects and enables application of those aspects appears to be more beneficial than either approach alone.

The results of this investigation strongly support the necessity of an explicit approach to nature of science instruction (Bell, et al., 2000; Shapiro, 1996; Bell, Blair, Lederman, & Crawford, 1999). Instructional activities consistent with currently accepted ideas of NOS (e.g., footprints activity, science process skills activities, discussions of controversial topics) were employed in all iterations of this investigation, but were not enough. The specific aspects of the scientific enterprise that characterize the nature of science should be addressed specifically in instruction.

Although further research is needed before generalizing these results to other situations, this investigation provides support for an explicit, context-based approach to nature of science instruction in the elementary science methods course. While explicit nature of science instruction situated in the context of science controversy produced the greatest gains in nature of science understandings, explicit nature of science instruction alone was nearly as effective. Science methods instructors whose time constraints preclude including detailed instruction on science content or on a particular science controversy may see gains in their students' nature of science understandings through the less-time intensive explicit approach alone.

Future investigations will need to further assess nature of science instruction situated within and without science controversies (e.g., genetic manipulation, cloning, nuclear energy, and evolution) in order to explore the generalizability of the findings reported here. It is also important before generalization that other group situations be investigated; secondary or inservice teachers may respond differently to NOS instruction combined with GCC/GW. Also, it is important to extend this line of research longitudinally to address the critical question of whether elementary preservice teachers are able to translate their nature of science understandings into classroom instruction.

In the end of the semester interviews with participants who experienced explicit nature of science instruction, we asked whether this project would influence their future teaching. Their comments indicated intent to incorporate these understandings into their teaching, as illustrated in the following comment:

> [Studying GCC/GW and the nature of science] makes you realize that science isn't always exact and so you have a responsibility to teach both sides and all angles of a scientific issue. (Post-1, Spring 2000)

We believe the approach of explicit nature of science instruction has great potential for developing elementary teachers with complete understandings of the nature of science, and that adding in science content such as global climate change/global warming strengthens the understandings of the participants. Not only do the participants gain understanding, but science also becomes more accessible and relevant. As the participant quoted above remarked while packing up her bookbag after the interview:

> It makes me want to go back and re-evaluate what I thought I knew and ask more questions. Like, it kind of awakens the scientist inside me . . . (Post-1, Spring 2000)

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BUILDING BRIDGES: USING SCIENCE AS A TOOL TO TEACH READING AND WRITING

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There are many reasons to consider the integration of science and language arts. The most compelling of these reasons is that there is evidence showing cognitive parallels between the two subjects (Baker & Saul, 1994; Glynn & Muth, 1994; Rivard, 1994; Romance & Vitale, 1992). However, whether there is equal developmental progress in both areas is still unclear. The focus of recent research has been upon using reading and writing to teach science. The results of this research has persuasively shown that there is a clear benefit to science comprehension when the integration of the two subjects is done with careful planning (Gaskins & Guthrie, 1994; Glynn & Muth, 1994; Keys, 1994; Romance & Vitale, 1992; Schmidt, 1999). What has not been investigated in-depth is whether reading and writing also show significant development through this integration. The shortage of adequate class time is a persuasive reason to combine subject areas, but at the foundation of quality learning in most subjects is the ability to read and write. It is important to focus upon the impact of the integration of these subject areas on the reading and writing objectives as well as the science objectives. Science-related issues arise throughout life and a student is better prepared to deal appropriately with these and other erudite issues when reading and writing for understanding are explicitly taught (Gaskins & Guthrie., 1994).

Purpose

Glynn and Muth (1994) state that "learning to read prepares a student for reading to learn" (p. 1060) and that "learning to write prepares students for writing to learn" (p. 1064). The question remains as to whether the procedure of learning to read and write can be done simultaneously with comprehension of informational content. Meaningful activities that teach writing and reading, such as searching through science text and writing a report, can be an excellent method for promoting language art skills but does not necessarily engage students in actually understanding the science concepts (Dickinson, Burns, Hagen & Locker, 1997). The use of interactive, inquiry-based science activities to create a reason for reading and writing could theoretically establish a methodical approach to learning that would benefit the development of these skills.

Background

Casteel and Isom (1994) emphasize the inter-related connection between the language arts and science in their statement that "one way to ensure improved science learning is to begin with what students know about the reading and writing processes" (p.538). Smith and Johnson (1994) believe that "literature can become the lens through which content is viewed" (p.198) and that the integration of curriculum sets the stage for students to read, think, communicate and make decisions about all kinds of information that they encounter.

While science and language arts may have objectives that are disparate (Dickinson & Young, 1998) there are also sub-structural elements in both which are analogous (Gaskin et. al., 1994; Romance & Vitale, 1992; Schmidt, 1999). Reading, writing and science all require a combination of the utilization of cognitive processes and the activation of conceptual knowledge. The cognitive strategies that are applicable to reading and writing are comparable with the strategies used to construct science understanding. A study done by Keys (1994) demonstrated a direct correlation between students' writing for structured investigation reports and the development of scientific reasoning skill. Casteel and Isom (1994) formulated an illustration of the supportive nature of literacy processes to science understanding that included predicting, organizing, questioning, and evaluating. The process of reading begins with identifying the topic of the text and then using relevant background knowledge about that topic; the initial step of experimenting in science involves identifying the problem and making connections and observations about it. Padilla, Muth, and Lund (1991) believe that "it would be naïve to assume that a one-to-one relationship exists among all the science and reading processes," but they also state that "several critical similarities exist" and that we can "use these similarities to apply the skills taught in science to comprehension of written assignments" (p. 17).

Research Questions

The process skills that science and language arts have in common are making and verifying predictions, making inferences, and drawing conclusions. It seems that the use of hands-on activities, which are inherent to a good science program, could provide a stimulating arena for the concurrent teaching of the basic skills in communication. Drawing upon the parallels between the two: How does the use of science topics during language arts instruction influence the development of reading and writing skills? Science can provide a purpose for reading and writing. How does the integration of them effect the students' reading choices and basic writing skills? How can I as a student teacher use science to improve reading and writing?

Procedures

Intervention

The setting of this study was a typical 5th grade classroom in Southeastern Washington. There were 27 students, 16 girls and 11 boys, between the ages of 10 and 12. The research was conducted during the solo-teaching phase of my internship. The intervention for this research was modeled after the PAR Lesson Framework that is outlined in Richardson and Morgan

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(2000). This framework for content-reading instruction included the following steps: *Preparation*, which considers textual features and student background knowledge, *Assistance*, where the instructional context for the lesson is provided, and *Reflection*, which provides critical thinking opportunities and openings for extension activities and enhancement (p. 6-7). Each of these steps included a writing segment, which focused upon the science topic that was being investigated.

During the Preparation portion the students performed hands-on science activities and experimentation. The reading material used for this investigation was the *Ecosystems* Student Activity Books (NSRC, 1996). They completed What-I-Know-Activity (WIKA) and Anticipation Guide sheets (Appendix A) to help preview and ask questions about the upcoming reading. The writing portion at this stage consisted of guided note taking in science journals (Appendix B) during experimentation activities as well as the completion of the pre-reading guides.

The Assistance step involved guided reading procedures that included pre- and post-reading activities with the whole class. Through the use of Venn diagrams for comparison and contrast, vocabulary lists, key concept clarification, and listing what the students learned from the reading I looked for inconsistencies and misinformation. Organizational charts that assisted the students to discover comparisons and contrasts were provided for them to complete during silent reading. "The teacher usually sets up the matrix and encourages students to fill it in as they read. In this way students understand the relationships and build meaning as they read" (Richardson & Morgan, 2000, p.170). These completed charts were used as study aides and included the social aspects of learning when groups or pairs of students filled them in. The important vocabulary words were discussed and placed on a chart in the classroom.

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The Reflection phase took place when students were given the opportunity to ask themselves what they learned and demonstrate their learning by writing a formal paper on the topic studied. Using the notes from their science journal, the organizational charts and the Student Activity Books as informational sources the students concluded the unit with a one page expository paper. Preparation for this final paper included writing several drafts of a business letter, writing a descriptive paragraph, and a compare and contrast paragraph. The first topic, "What We are Doing in Science," was used to model for the whole class how to write a letter to the principal to explain what they had been studying. This model included two paragraphs that each had a topic sentence, supporting details and a concluding sentence. After demonstration of the format of a business letter, each individual student wrote a letter. A modified rubric that is based on the six writing traits was used to score the papers (Appendix C). The original rubric that this rubric was modified from was obtained from the website, which is published by the Jericho School District in New York. It is aligned with the Washington State EALR numbers: 1.1, 1.2, 1.3, 2.2, 2.3, and 4.1. Also, in accordance with component numbers 3.1, 3.2 and 3.3 of the writing EALR's the intervention process included turning in rough drafts and revisions as many times as necessary (Appendix D).

Data Collection

The data collection techniques that I chose for this research included the following: (a) collection of student papers prior to intervention, during the instruction phase and their final drafts, (b) my daily journal in which I recorded observations of the implementation of activities, (c) 16 hours of video-taped sessions that specifically recorded student investigations prior to writing their papers and science and language arts instruction, (d) collection of the student science journals, and (e) a weekly checklist that recorded book choices which were made by the students during free reading time (Appendix E). The journals were not graded for conventions, sentence fluency or word choice. These journals were intended to be a forum for the students to integrate the interactive, inquiry-based science activities with the information from reading into an informal written format. The process skills that language arts and science have in common, questioning, predicting, organizing, and evaluating, were all included in the Note Taking Guidelines (Appendix A) which were used as writing prompts in the use of their science journals. The timeline for data collection is shown in Figure 1.

Data Analysis and Relationship to Purpose

I performed a general screening of the five data sources collected to determine whether the use of science as a topic had encouraged students to focus on using reading and writing to process meaningful information. The formal expository essay was evaluated according to the guidelines defined in the rubric and was a tool for the final assessment of the impact of the integration of the science activities and writing instruction. I sought patterns of change in writing samples and scores from the rubric.

The science journals were considered for their formative value in determining student understanding. The note-taking guidelines were supposed to provide a format to estimate whether the student is on track in their science learning or if they need to be guided to texts that would enhance their understanding.

Videotapes of the instructional and investigative stages of this research project were used to verify that the process was being implemented successfully and provided a method of self-evaluation of the methods that were used to instruct. The videotapes were viewed with the objective of noting the student use of reading materials to satisfy an inquiry. I looked for patterns in the videos that would indicate the impact on reading once a purpose had been provided by the science investigations. The use of the Anticipation Guide and What I Know Activity sheets were specifically videotaped to determine their effectiveness in assessing the students reading for comprehension.

Comparative tabulation of the book choice checklists was an assessment of whether there was an increase in students who selected non-fiction books for obtaining information during free reading time. This would be an indication that the reading was being done to seek explanation and meaning. Reading for a purpose has been shown to increase comprehension (Gaskins & Guthrie, 1994; Keys, 1994; Schmidt, 1999).

An analysis of the student papers and their rubric writing scores, triangulated with an investigation of the video tapes and my teaching journal, the book choice checklists and the student science journals was used to validate whether the science topic had impacted the students' reading and writing skills. I also sought counter-examples in the students' work to look for patterns that would further validate my study.

Outcomes

Conclusions and Implications

Within the first two weeks it became obvious from review of the videotapes and my teaching journal that the integration of reading with science and the integration of writing with science would need to be dealt with as two separate issues. From the onset there was significant success in the integration of reading with science and very little development in merging writing and science. There were several indicators that the integration of reading and science was advantageous.

The successful achievement of science objectives using reading as a tool (Romance, 1992) supports the implication that there should also be a corresponding benefit to language arts.

The processes that are intrinsic to efficient science comprehension are compatible with the processes that increase reading skills. Baker (1991) asserts that "one of the most important self-regulatory skills for reading is monitoring comprehension, which involves deciding whether we have understood (evaluation) and taking appropriate steps to correct whatever comprehension problems are noted (regulation)" (p.3). Evaluation and regulation are essential components of both science and reading. The goal was to encourage students to utilize reading strategies in their attempt to make sense of the science topics, and as a result refine those reading skills as well.

A videotaped session verified that this does occur, but that the students needed to be prompted by the teacher before they would use the text to investigate a question. During the process of creating a Venn diagram of the similarities and differences of aquarium and terrarium animals a question was raised as to whether snails had eyes. There was an illustration in the text that the students had already read, but a very vocal debate ensued among the students. At my prompting a student retrieved the text and looked up the answer and read it aloud for the class. Another incident occurred in which several students were arguing that the jelly-like masses in their ecocolumn were snail eggs, and again, when they turned to me for verification I directed them to the text. This incident was particularly encouraging because they read beyond the information that they were seeking and added new knowledge about the reproduction of the fish as well as the snails.

Further evidence that science and reading instruction are compatible is extracted from the analysis of the Anticipation Guide and What I Know Activity (WIKA) sheets. The Anticipation Guide prediction that a statement related to the science reading was a fact resulted in an average of 68% correct *before* the reading. The percentage that was correct *after* the text had been read increased to 92.3%. These percentages remained generally consistent for three separate Anticipation Guide science-reading assignments. The WIKA reading worksheets asked what the student knew before the reading, what they knew after looking at the text with its pictures and diagrams, and what they knew after they read the text. The final section of WIKA asked the students if there was anything that they still were wondering. Comparative analysis of these sections gave evidence that the reading was used to process science information during the act of reading. The first time in which they completed the WIKA activity sheet, ten students were able to correct misinformation that they written in the first section (that isopods are insects) after they had completed the reading (they are related to lobsters). There were five students who did not correct their erroneous information after reading. The second time that the students completed the WIKA assignment there were thirty-eight incidents in which students corrected misinformation statements and six that remained uncorrected. The relevancy of the questions that the students posed in the last section was inconsistent, with twenty-seven questions being posed that were relevant and fifteen questions that were either extraneous or were answerable from reading the text. The shared metacognitive skills, in both reading and science, of posing and verifying predictions, making inferences and drawing conclusions (Padilla et. al., 1991), resulted in the data demonstrating a direct and beneficial correlation between them. Teaching students the reading strategies of how to preview a text and seek specific information was very compatible with science. Figure 2 shows a listing of results related to the advantages and disadvantages of integrating reading and science.

The evidence from the videotapes and journal entries that students needed to be prompted to expand scientific information from a text was verified by a review of the book choice checklists. The data collection was somewhat inhibited by the fact that there was no classroom library and the students were only allowed to visit the school library on Friday. This data was further skewed by the inconsistent number of Fridays during this research due to two snow days and two district workdays. The number of non-fiction books checked out by the students over the course of the implementation showed a slight, but negligible, change.

A further review of the book titles revealed that there were only 4 out of the total 67 non-fiction books checked out that could be viewed as books that were related to our specific science topic. Triangulation of the book checkout data with my teaching journal, which recorded a discussion with the school librarian requesting a display of relevant books, revealed that the high of 12 non-fiction books checked out at the end of February was prompted by that visual display. Previous to attending that library session they also received verbal encouragement from me to consider those books. See Figure 3 for a graphic representation of books checked out.

The integration of the writing instruction with science became problematic during the Preparation stage of this research. In accordance with the PAR (Preparation-Assistance-Reflection) plan the students were given a science journal to record their hands-on activities during this initial stage. The note taking guidelines were introduced as an guide to help them get started taking notes but were not a requirement; they should feel free to write whatever they considered significant. After they had been writing in their notebooks for a week and a half I stipulated that they were now *required* to use the guidelines and it had the negative effect of reducing the amount and the insightful aspects of their writing.

This is an example of a science journal entry (complete with grammatical and spelling errors made by the student) **without** the guidelines:

> Hand lense Investigations
>
> In the terrarum I see lots of of roots sprouting in the mustard spot, and the Alfalfa. In the Alfalfa I think I buried it to deep. I wounder why the grass is not sprouting, maybe I didn't plant them well. It's weird because not all of the mustard seeds are growing, and most of the Alfalfa seeds are (Watered it 11 times) In the aquarium they'res buble

> everywere for some reason. From the Algae the water looks more dirty. Looking through the lense the water looks like it has little pieces of hair in it. I think the Algae is making the water smell like its from the river. I have been woundering why they call duckweed duckweed but it's because ducks eat it and other animals

After I began **requiring** the students to use the note taking guidelines the same student made this entry in her journal:

> 1. Today we aereated our aquarium. When we put air in it the fish swam close to wear we were aereated also the duckweed started geting closer. 2. I think we may have babie snails their 3. I have observed poop on some leaves. Relly small so I'm not sure. 4. I'm not sure if anytthing is going to happen 5. Nothing really happened 6. Same 7. I think we are going to add duckweed again in a few weeks. 8. there is a drawing at the top ^ 9. I'm still wondering if we have babie snails.

This example of the reduction in the quality of the processing of their science thinking was replicated in student after student. Instead of using the guidelines as prompts to write more, they simplified their answers to basically yes or no type responses, with less detail. The impact on science as well as the volume and quality of the writing was negative.

During the Assistance phase I modeled how to write a two- paragraph business letter to the principal using a topic sentence, supporting details and a concluding sentence for each paragraph. I also directed the students to use the vocabulary lists and science charts that we had created as a class to get information for their individual letters to the principal. The first draft that was turned in astounded me in the lack of ability in writing. Of the 22 letters that I received there were only two that followed the guidelines which required that both paragraphs had a topic sentence, supporting details and a concluding sentence. All of the letters contained misspelled words that were part of the environmental print. The subsequent corrections and requirement to re-write was met with great dismay on the part of the students. There were 10 students who had to write more than two drafts.

The next assignment, to write a descriptive paragraph with the writing prompt "Imagine that you are an animal in your ecocolumn and describe a day in your life," was meant to simplify the task of writing to one basic paragraph. The first draft of this assignment was even more alarming in the lack of structure. It became apparent to me that these students would need basic instruction on how to formulate a paragraph. The following is an example turned in from a high achieving student of the rough draft of her descriptive paragraph:

> Hi! My name is Manpie but there are these two girls that are big, huge hue-hue-humans. They call me small and my partner big. We hate it. When we're all sound asleep they always tap our container and wake us up. By the way did I tell you we are in this small container that bugs us. It really hurts when they knock it over. Well I go the yans and It's getting dark. So see you later. Bye.

Again, the number of times that many of the students had to rewrite their paragraphs was discouraging to them. They quickly lost interest and enthusiasm for the topic of science. There was clearly a gap in the objectives that needed to be achieved in writing and the objectives that had previously been progressing well in science. I made the decision at this point that it had become necessary to separate the two subjects to maintain growth in both areas.

I began to implement a highly structured sequence of instructions for writing called Power Writing. This teaching structure introduced by J.E. Sparks in his book *Write for Power* assigns a number value to words, phrases and sentences. It helps keep the writer on topic and teaches a way to organize thinking into cohesive, logical paragraphs. There are five stages that a student must go through before they are ready to write a paper. Because of the necessity for repetition to obtain mastery I decided to allow the students to pick a topic that interested them while they were progressing through the first four of the five stages. In spite of high interest and involvement in the class science activities, not one student chose to write about science. After three weeks of intensive instruction in writing I returned to the topic of science and assigned a paragraph that would compare and contrast the aquarium and terrarium environments of their ecocolumns. It was encouraging to see the average grade for the final draft increased to 92.1%. However, the impact of imposing this very defined written structure upon on the science topic resulted in paragraphs that were nearly identical and limited the science information processing.

The final four-paragraph essay assignment was meant to be an instrument to help determine whether the merging of the science topic with writing requirements was successful at the final stage of instruction. The following is two of the four paragraphs of an essay titled "What We Did In Science:"

> In science we made an ecocolumn. We built a terrarium and an aquarium. We did this so we could see how our world works. We also polluted our classroom ecosystems.
>
> The reason we did this science experiment was so we could see how our world works. For example, we have a lamp for the sun, which evaporates the water from the aquarium into the terrarium. It then forms clouds and since it's in a bottle and it's covered, just like our world, it then rains. This means that we don't need to water it.

The results of this essay were much more satisfactory in their adherence to basic grammatical structure and the actual learning that had occurred in science became more evident.

The evidence from the writing portion of my research suggests that teaching students the basic skills of how to write well is not necessarily compatible with instruction in science. The science concepts seemed to lose impact and importance to the students, when they were required to re-write, re-word and edit their papers. Writing was an effective medium for them to demonstrate and summarize their science learning, but the instruction phase of writing needed a variety of topics to keep the students engaged and motivated. There was distinct disadvantage to science learning that resulted from the total integration of science and writing.

The implications for the results of this research in my own teaching are that it has a decided influence upon whether, and to what degree, I will integrate reading and writing and science in my classroom now that I have moved beyond my student teaching. It seems logical to integrate reading and science since it appears to be a very effective way to teach students the strategies for reading to obtain information. However, reading to obtain information is only one of the objectives of reading and there are many reading skills and strategies, such as interpreting a poem, that would be difficult to integrate with science. Evidence from my research indicates that the integration of writing instruction and science should be done in the final stages of the writing instruction. The complex goals and objectives of writing can have the effect of suppressing the cognitive processing of science concepts. The successful implementation of reading and science that is demonstrated in this research could influence other teachers by clarifying the degree in which the integration of the two subject areas should be cultivated. Although the existing research base demonstrates that there is a clear benefit to science when writing and reading are integrated with it, this current study indicates that the development of reading and writing should cover a wide range of subjects in addition to science in order to be effective. The cognitive parallels that exist between science and reading and writing do *not* outweigh the conflicting objectives that sometimes arise. This research indicated that interdisciplinary instruction should be approached with a clear idea of the objectives in all of the areas, and a willingness to separate the subjects when it is beneficial to their development. These results can be generalized to many elementary classrooms and it is evident that instruction in reading and writing are bridges to virtually all of the subject areas and should not be confined to science alone.

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Appendix A

Sample What I Know Activity Sheet and Anticipation Guide

WHAT I KNOW ACTIVITY SHEET: ___TOPIC_____

What I know about______ ______	What I know about______ ______ after preview	What I need to know as I read	What I know after reading	What I still need to know

---

Anticipation Guide: ____(topic)_________

Instructions: Before reading pages ____ through______ in *(name of text)*__ place a check mark in the space to the left of each of the statements with which you agree. Then during the reading, place a check on the right of the ones you find to be true. BE SURE YOU ARE ABLE TO REFER BACK TO THE TEXT TO PROVIDE EVIDENCE FOR OR AGAINST EACH STATEMENT.

true	false	True or false statement from text.	true	false

Appendix B
Guidelines for Taking Notes

Note-taking guidelines

1. What did you do? What things did you notice when you did it?

2. What changes were made?

3. What are some things that you have observed?

4. Describe what you thought would happen.

5. What actually did happen?

6. Why do I think that it happened like that?

7. What do you predict will happen next? What do you want to make sure that you record accurately so that you can notice changes.

8. Is there a drawing or diagram that will help demonstrate what happened?

9. Are there some things that you are still wondering about? Where can you find more information about this?

Appendix C

Writing Rubric

http://www.bestschools.org/seaman/classrooms/reading/writing.rubric,

Jericho School District, New York

	WOW!!!	YES!	OK	OOPS!
	4	3	2	1
FOLLOWING DIRECTIONS **Did I follow directions?**	•follows all directions	•follows most directions	•follows some directions	•follows few directions
MEANING **Did I show understanding?**	• shows insightful understanding of important ideas	• shows understanding of most of the important ideas	• shows partial understanding of important ideas	• show no understanding of important ideas (misses the point)
Did I make clear connections?	•makes strong connections and reflections	•makes a few connections and reflections	•makes weak connections and reflections	•makes no connections or reflections

SUPPORTING DETAILS Did I develop my writing?	• uses specific details and accurate examples	• uses adequate examples and details	• uses minimal details and examples	• uses few or no details and examples
ORGANIZATION Did I organize my writing?	• shows strong organization with beginning, middle, and end	•shows good attempt at organization	• shows some organization	• shows no organization; confusing
EDITING Did I edit my work?	•no errors	•few errors that affect meaning	•some errors that make meaning unclear	•many errors that make meaning unclear
Spelling	• misspellings only on challenging words	• misspellings on some basic grade-level words	• misspellings on many basic grade-level words	• misspellings make meaning unclear
	WOW!!!	YES!	OK	OOPS!
	4	3	2	1

Appendix D
Washington State Essential Academic Learning Requirements

Washington State EALR's

Writing

1. The student writes clearly and effectively.
W1.1 develop concept and design
W1.2 use style appropriate to the audience and purpose
W1.3 apply writing conventions

2. The student writes in a variety of forms for different audiences and purposes.
W2.1 write for different audiences
W2.2 write for different purposes
W2.3 write in a variety of forms
W2.4 write for career applications.

3. The student understands and uses the steps of the writing process.
W3.1 prewrite
W3.2 draft

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W3.3 revise
W3.4 edit
W3.5 publish

4. The student analyzes and evaluates the effectiveness of written work.
W4.1 assess own strengths and needs for improvement
W4.2 seek and offer feedback

Appendix E
Book Choice Checklist

		Non-Fiction?	
Student Name	**Book Title**	**Yes**	**No**

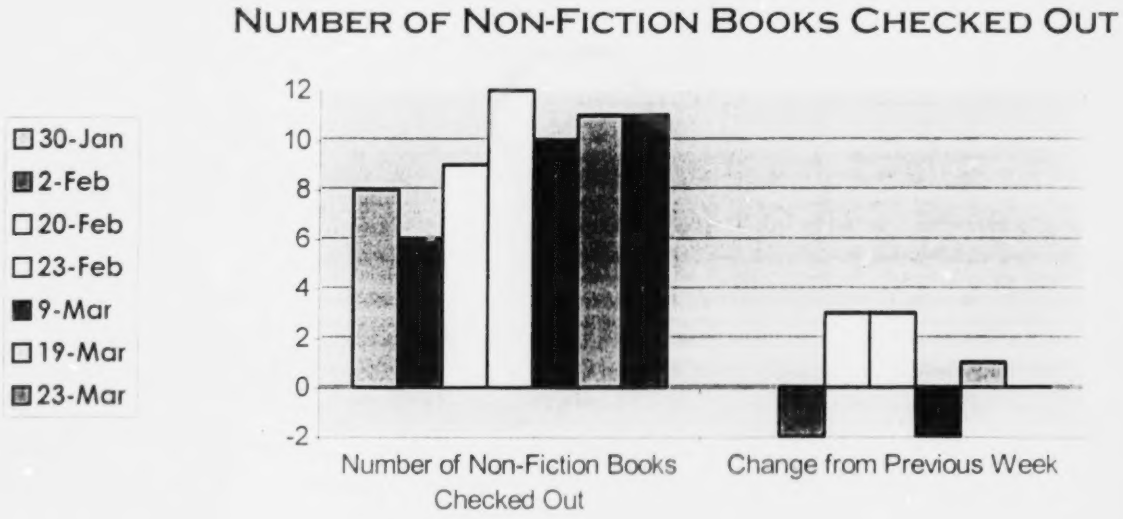
Figure 1. Timeline for Data Collection

WEEK ONE & WEEK TWO	• Recorded observations in journal • Video taped during language arts and science instruction time • Collected two book choice checklists
WEEK THREE	• Recorded observations in journal • Video taped group instruction of letter to principal • Implemented and collected student science journals
WEEK FOUR	• Recorded observations in journal • Video taped student investigations & research • Collect student science journals • Collected two book choice list • Collected rough and final drafts of individual letters to principal
WEEK FIVE	• Recorded observations in journal • Video taped student investigations & research • Collect student science journals • Collect one book choice checklist • Collected rough and final drafts of descriptive paragraph
WEEK SIX, SEVEN & EIGHT Separated Writing and Science Instruction	• Recorded observations in journal • Collect student science journals • Collect one book choice checklist • Power Writing Instruction
WEEK NINE & TEN Reintegrated Science and Writing Instructions	• Record observation in journal • Collect and conduct student self-evaluation of science journals with rubric • Collect one book choice checklist • Collected rough and final drafts of Power Writing Compare and Contrast Paragraph and 4-paragraph Expository Science Essay

Figure 2. Advantages and disadvantages of integrating reading and science.

Integration of Reading and Science	
Advantages	Possible Disadvantages
• Students learned to preview texts before reading.	• Students needed to be prompted to use a text to answer questions.
• Students gained skills on how to read to obtain information.	• Self-selection of non-fiction books showed no significant change.
• Reading and Science objectives of students *verifying predictions* were met. • The majority of the students self-corrected misinformation.	• A multitude of aspects related to reading was not addressed due to the limitations set by science objectives. (creative, reader response, poetry, etc.)

Figure 3. Number of non-fiction books checked out over the course of the study.



INTEGRATING A SCIENCE CONTENT COURSE AND A COGNITIVE DEVELOPMENT COURSE FOR PRE-SERVICE EARLY CHILDHOOD TEACHERS: BARRIERS AND BENEFITS

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The National Science Education Standards state:

> Effective science teaching is more than knowing science content and some teaching strategies. Skilled teachers of science have special understandings and abilities that integrate their knowledge of science content, curriculum, learning, teaching, and students. Such knowledge allows teachers to tailor learning situations to the needs of individuals and groups. This knowledge called "pedagogical content knowledge," distinguishes the science knowledge of teachers from that of scientists. It is one element that defines a professional teacher of science. (NRC, 1995, p.62)

Further, Professional Development Standard B from the same document recommends learning experiences for teachers that integrate science content and science education in authentic contexts, inquiry, reflection, interpretation of research, modeling and guided practice. However, how can this be accomplished, even at a novice level, within a pre-service teacher education program? In a typical program, knowledge bases are learned in separate courses, and the students are expected to integrate these knowledge bases during the act of teaching and during reflection upon teaching experiences. These acts of teaching may occur during pre-service field experiences, the final student internship, or during the early years of teaching after licensure.

This model for the development of pedagogical content knowledge (PCK) has been called the Integrative Model (Gess-Newsome, 1999). Teacher preparation programs organized by this model require students to obtain knowledge in subject matter, teaching methods and classroom contexts and to obtain the skills to integrate these knowledge bases later during the act of teaching. Another model described by Gess-Newsome is the Transformative Model. This model advocates teaching the knowledge bases in an integrative fashion that develops a synthesized knowledge base for PCK. Therefore, PCK exists as a separate knowledge domain that can be used by teachers to justify instructional decisions. Teacher preparation programs based on this model would facilitate the integration of the knowledge bases by focusing on best practice. Both models have difficulties. The Integrative Model, as currently utilized, does not seem to adequately facilitate the integration of knowledge bases because it primarily leaves it up to the student. It is assumed that since the students have these separate knowledge bases, they will be able to integrate them in complex situations. The Transformative Model could lead educators to teach PCK as a separate knowledge base, consisting of best practice under a variety of circumstances. This reduces the requirement that knowledge bases be integrated during the act of teaching, but this method could reduce the teacher's role to simply identifying the most appropriate best practice for a given set of instructional circumstances and, in fact, inhibit reflective practice. In addition, the model seems to underestimate the complexity of teaching and the flexibility of thinking that is required for effective teaching.

This paper will discuss our attempt to modify the Integrative Model, as currently practiced, by providing experiences that help establish connections between science content, how children learn, and developmentally appropriate practices. As students accomplish these tasks we hope that they will gain skill in integrating knowledge bases. Team-teaching a science content course and a cognitive development course facilitated the process. During the courses, students experienced science inquiry, conducted an inquiry on what children think about light by interviewing young children, discussed developmentally appropriate practices in the context of teaching science, and facilitated a modified Project Approach (Helm & Katz, 2001) in which they designed, implemented, and evaluated instruction with young children at their field site. The paper will also discuss the rationale of the integration and describe the process of designing and implementing the course. In addition, the barriers and the benefits of the project will be discussed.

Context

Northeastern State University (NSU) is a regional university in rural, northeastern Oklahoma. The institution had its beginnings in 1846 when the Cherokee National Council authorized the establishment of a National Male Seminary and a National Female Seminary. The primary mission of the Cherokee National Female Seminary was teacher preparation. The State of Oklahoma established Northeastern State Normal School in 1909. Today, NSU is a comprehensive, primarily undergraduate university that continues to focus on teacher preparation. NSU is located in Tahlequah, Oklahoma, the Capital of the Cherokee Nation and prepares more Native American teachers than any other university in the United States. The College of Education is the largest college on campus. However, methods courses for specific content areas are primarily located in the content colleges. For instance, science education methods courses are housed in the College of Math, Science, and Nursing and taught by science education faculty who are members of the College of Math, Science, and Nursing. Most of the students are non-traditional and commute an hour or more to attend classes. Many of them have children and also work outside the home. Most have limited preparation in math and science.

The Courses before Integration

The courses Science in the Elementary School and Cognitive Development of the Young Child are typically taught as separate courses by a science faculty and an education faculty respectively. The science faculty member who participated in the integration of the courses has a strong science background and holds a doctorate degree in Curriculum and Instruction. Her public school science teaching experience is in grades 9-12. The science course is a requirement for Elementary Education, Early Childhood Education, and Special Education majors. The instructor was already attempting to integrate science content and pedagogy by utilizing alternative framework research. Each science content unit included a summary of what children think about the science concepts taught in that unit. The instructor summarized research findings cited in *Children's Ideas in Science* (Driver, Guesne, & Tiberghien (Eds.), 1985). In addition, teaching science content through hands on activities and inquiry was regularly modeled and discussed explicitly, and students prepared unit plan in order to help them learn to integrate science content knowledge and knowledge of pedagogy.

The education faculty member holds a doctorate degree in Curriculum and Instruction with an emphasis in Early Childhood Education. She has public school teaching experience in grades K-5. The course focused on the cognitive development of children in the early grades (3 year olds through 3rd grade). However, the instructor provided content areas, such as math, science, and social studies, in which to discuss developmentally appropriate practices. She placed special emphasis on facilitating science instruction. Students participated in an assignment that focused on the Project Approach to demonstrate their understanding of content knowledge, pedagogy, and developmentally appropriate practices.

The Integrated Courses

The education faculty member approached the science faculty member about integrating the courses. Both instructors saw potential benefits for the students. The primary benefit seemed to be expanded opportunities to integrate knowledge bases concerning science content, how children learn, and developmentally appropriate practices. The individual courses already overlapped. For example, in both courses students were investigating Piaget's developmental stages by performing conservation tasks with young children. Students were writing lesson plans/unit plans in each course. In addition, many of the concepts addressed in both courses were influenced by science content and by the developmental stages of children.

There was administrative support for the project. Both the Dean of Education and the Dean of the College of Math, Science, and Nursing supported the project and arranged for the courses to be block scheduled so that we would have more time for field experiences. The instructors applied for and received a university Innovative Teaching grant funded by the Faculty Research Committee to purchase supplies and materials for the project, and an ongoing National Science Foundation sponsored teacher education initiative (Oklahoma Teacher Education Collaborative) provided summer pay for course development.

The students were required to enroll in specific sections of both courses. They needed to be admitted to the Teacher Education Program prior to enrollment. Due to scheduling difficulties, which will be discussed below, only five students enrolled.

The innovative aspects of the program included multiple field experiences, team teaching, joint course assignments that were assessed in both courses, extensive collaborative planning for instruction, and collaborative evaluation of instruction. The purpose of the team teaching and joint course assignments was to provide a classroom environment that facilitates integration of ideas and the expression of differing viewpoints. For even though the instructors had common goals, they each had different points of view. Class discussion was often centered on how to present science concepts in a developmentally appropriate manner and the value of science inquiry to the development of young children. In addition, students were assigned tasks that were designed to integrate knowledge bases. These tasks and their expected benefits are summarized in Appendix A. Most of them were accomplished during the five field experiences that were incorporated into the course. Each student was assigned to a classroom. Student interest was accommodated whenever possible.

Inquiry Based Instruction

Science content concerning light, heat, magnets, sound, and weather were taught using inquiry-based instruction. The inquiries centered on answering questions using hands on activities. Classroom discussion was then used to compare findings and reconcile them with what is known about the science concepts under investigation. It was hoped that teaching the content by using inquiry would help the students to understand the concepts more fully and in a more meaningful way, to develop science process skills, and to better understand the nature of science. In the process, an attempt was made to make the science process skills and the nature of science and scientific inquiry explicit through classroom and group discussions. Although the content was taught at the undergraduate level, it was hoped that students would come to understand the importance of teaching science content through inquiry.

Student Interviews of Young Children

As a part of the light unit, students were asked to interview young children concerning their understanding of light. They interviewed the children during their first field experience. Before the interviews they decided what aspect of light to investigate and chose a hands-on experience to both interest the students and assess their current understanding. Students chose reflection of light off a mirror, how shadows are formed, or the separation of white light into colors. After choosing the aspect of light that wanted to investigate, they selected an activity that would allow them to assess the understanding of the children. For instance, one student investigated their understanding of reflection by asking students to predict where the light from a flashlight would shine if the flashlight is aimed at a mirror. Most of the students were able to conduct these interviews during regular center time at the field site. After interviewing children, students were asked to reflect on their experience and discuss the understanding the children had about light and how that understanding might be influenced by their developmental stage. In classroom discussion, the student results were discussed and compared to the finding of Guesne (1985}.

The purpose of this assignment was to help students learn to recognize misconceptions young children have concerning light and to help them understand how misconceptions may be influenced by children's developmental stages and prior experiences. In order to accomplish the task however, students needed to understand something about light, to be able to communicate with young children, and be able to probe and understand children's thinking. The fact that it took place in a classroom context helped make the experience more authentic and relevant.

Modified Project Approach Experiences

Students conducted a modified Project Approach based upon the work of Helm and Katz (2001). They define the Project Approach as an in-depth investigation that is focused on questions about a topic. These questions may arise from the children, the teacher, or from some interaction between the teacher and children. The Project Approach differs from a thematic unit in that it is focused, not on a theme, but on questions that are worth investigating about a specific topic. Typically the project will have three phases. Phase One involves the children in the project by carefully determining what they know about a topic of interest and what about the topic sparks their curiosity. This is the time in which children become engaged in the project and help determine the questions the project will investigate. Phase Two is the investigative stage of the project in which children actively engage in finding answers to questions. Phase Three is the conclusion of the project. It usually focuses on a culminating event or activity that enables the children to share what they have learned.

As described by Helm and Katz, the Project Approach is a long term, student centered investigation in which children are actively engaged. Typically such a project would originate from the children's interests and would last several weeks. However, our students would have to complete a project in only three visits to the field site, and we wanted their project to be specifically a science inquiry. Therefore, it was necessary to modify the Project Approach to meet our students' needs. Students had two prior field experiences in which they were able to meet and work with the children. These visits also gave them time to observe their teacher's routines and procedures and to ask her about student interests and prior experiences. Then the students each selected a topic for their classroom and planned the Phase One activity that they would use to determine what the children already knew and the children's questions about a science topic. They then assembled some learning experiences for Phase Two that they thought would help the children answer some of their questions; conducted the inquiries with the students; and then documented what the children had learned as a result of the inquiries. Each student wrote a paper that documented their reflection upon the process of inquiry, the children's new understanding of science concepts, and the role of the teacher in facilitating learning in a developmentally appropriate manner.

This project seemed to be a valuable task that would require students to access multiple knowledge bases. The purpose of Phase One was to help students develop confidence in their ability to facilitate an open ended science inquiry based on children's interests and to access children's prior knowledge concerning science concepts. During this process we hoped that students would recognize the importance of science content knowledge in providing developmentally appropriate practices. After all, how could they determine what children know and what questions were worth developing a project to answer if they did not know anything about the science topic? The purpose of Phase Two was to give our students the opportunity to develop experiences that facilitate the understanding of science concepts in a meaningful way and to provide experiences for young children that facilitate science inquiry. Once again students would have to access more than one knowledge base in order to accomplish their goals. Finally, the purpose of the documentation was to facilitate reflection upon the integrative nature of the teacher's role in facilitating learning. In addition, the documentation was to build student confidence by providing closure that focused on the completion of a complex learning task.

Evaluating Science Learning Activities

In this final task, students were asked to evaluate whether learning activities are developmentally appropriate and foster understanding through inquiry. This task should require the students to access knowledge bases concerning science content, how children learn, and developmentally appropriate practices, thereby helping them develop skills in integrating knowledge.

Barriers

NSU was an ideal place to integrate these courses. The structure of the university itself and the strong emphasis on elementary education at this institution reduced many barriers that would probably exist at other institutions. Having science education faculty teaching science content courses to early childhood majors certainly facilitated this project. However, in spite of strong institutional support, the project encountered some administrative difficulties. The biggest problem was that the students had to be concurrently enrolled in both courses. This was essential because of the joint projects and extended time for field experiences. Some students were unable to concurrently enroll because they had already taken one of the courses or because they had a scheduling conflict with another course they must take that semester. In addition, there was no way to prevent students from enrolling in the course even if they did not fulfill prerequisites because students enroll by phone automatically. Therefore, we had to inform many students by phone that they needed to enroll in both courses or that they could not take either course. In addition, some students elected to take the courses separately at another NSU campus even though they were eligible to enroll. The result was that only five students enrolled in integrated courses.

The time required for the integration and team-teaching of these courses is an additional barrier. We were willing to put in the extra time because we wanted to see if integrating the courses would in fact help our students integrate knowledge bases, however the project was time intensive. Along these same lines, one of our students commented that she was concerned because she was not doing as well in one of the two courses and was unable to drop one without dropping the other. Some faculty advisors have expressed concern that the scheduling of classes is more difficult because of the integration of the courses. It remains to be seen if the courses can remain as they are. Certainly the number of students enrolled needs to increase for the integration to remain viable.

Finally, there were unexpected knowledge barriers for the instructors. The goal was to help students integrate knowledge bases, but this was hampered by the fact that each instructor had different knowledge bases themselves. They overlapped in some areas, but not all areas. Therefore, the integration had to occur in accomplishing a task. This meant that the integration sometimes happened through extensive pre-class discussion and sometimes it happened in class during instruction. For instance, the education instructor wanted to use the Project Approach as a framework for the student designed instructional unit, but the science instructor had never used this framework or seen it done by someone else. The resulting assignment turned out to be harder than either instructor had imagined. In spite of a great deal of planning, much of the integration of knowledge bases occurred during classroom discussions of the difficulties the students were having in completing the assignment.

Benefits

One of the benefits of the integration was that our students began to realize the importance of understanding science content. This was a painful experience for some because, like many elementary education majors, our students felt that they did not know very much about science. One student commented during the planning of the Project Approach,

> I guess that it is the science part that gets me is that the point keeps being stressed that to do a certain subject you better know a lot about it. Well I know a little about a lot of things, but I don't know a lot about nothing (sic), especially not science.

Another student responded,

> That is why I keep retreating back to sound or light, which we have covered extensively in our science class because I can do something…

While the students were frustrated at this point, they were all able to complete the assignment. However, it is interesting to note that they all chose content areas for their projects that had been previously taught in class using inquiry-based instruction. Three students did projects on magnetism, one student did her project on sound, and one student did her project on light. We were in fact studying magnetism during the bulk of the planning.

There are also indications that some skill integrating knowledge bases may have been developed. On the cognitive development course final, students were asked to pretend that they were first grade teachers, who used developmentally appropriate practices to teach science and to describe how they would reply to another teacher, named Mrs. Jones, who asks them, "Why are you wasting your time on these science activities? Science is too hard for children to understand, plus we have too much curriculum to cover already." The responses indicated that all of the students were able to integrate knowledge bases to answer this question. Some excerpts from the responses of three of the students are given below.

> Student One: I would tell Mrs. Jones that children are interested in science, and that many of the questions they ask could actually be turned into hypotheses and tested. For example, if Sammy asks why all of his paints mixed together on his paper looks black, as a teacher I can use this opportunity to help him discover color and light mixing, and help him figure out how to make a simple chart to record his data. By using hands-on materials and listening to children's questions and interests I will know how to captivate the attention of the learners in my class, and give them the opportunities they need to make discoveries and to construct knowledge.
>
> Student Two: Of course the whole inquiry process includes many science processing skills that the children come to learn in the most natural way. They learn all of these things and are able to use them because they are able to relate them to life. They questioned why magnets would not pick up paper but magnets would hang their artwork on the refrigerator. Using this life experience they investigated and discovered that the magnets attraction to the refrigerator was strong enough to hold the paper on it.
>
> Student Three: As they ask questions, we will assess what they already know and build on this knowledge as we set up experiments and record our findings. These hands-on activities help the children to relate these science concepts to their real world. Also as they work together on projects and experiments, they will be in situations where they must defend what they are thinking and may discover that their ideas need some modification. As children learn the basics of inquiry and experimentation, they are learning how to be independent people who will make well informed decisions.

Finally, one of the greatest benefits was to the instructors themselves. While we were attempting to help our students integrate their knowledge bases, we in fact extended and integrated our own knowledge. The integration seemed to occur while we were engaged in complex problem solving. However, it also seemed to happen during reflection, planning, team teaching, and observations of the other instructor teaching. This may be an indication that our initial premise that a task can be used to integrate knowledge bases and thereby develop integration skills was correct.

This project was supported in part by the Oklahoma Teacher Education Collaborative (a National Science Foundation funded project) and a grant from the Faculty Research Committee of Northeastern State University.

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Appendix A

Tasks Designed to Integrate Knowledge Bases and their Expected Benefits

Task	Expected Benefits
During inquiry based science instruction, students recognized science process skills and scientific ways of thinking.	• To recognize the benefits of inquiry based instruction • To make the nature of scientific inquiry explicit
Students interviewed young children concerning their ideas involving light.	• To recognize misconceptions concerning light • To understand how misconceptions are influenced by children's developmental stages and prior experiences

During Phase One of the modified Project Approach, students determined what children knew about a science content area and determined what children were interested in learning about.	• To develop confidence in their ability to facilitate an open ended science inquiry based on children's interests • To be able to access children's prior knowledge concerning science concepts • To help students recognize the importance of science content knowledge in providing developmentally appropriate practices
During Phase Two of the modified Project Approach, students were participants in inquiry-based explorations with young children.	• To develop the ability to provide experiences that facilitate the understanding of science concepts in a meaningful way • To provide experiences for young children that facilitate science inquiry

Documentation of the modified Project Approach was a reflection upon the process of inquiry, the children's new understanding of science concepts, and the role of the teacher in facilitating learning.	• To facilitate reflection upon the integrative nature of the teacher's role • To build confidence by providing closure on a complex learning task
Evaluating whether a science learning activity is developmentally appropriate and fosters understanding through inquiry.	• To develop skills required for integration of knowledge bases

USE OF SCIENTIFIC INQUIRY T EXPLAIN COUNTERINTUITIVE OBSERVATIONS

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Background

The National Research Council (1990, p. 6) concluded that "... no reform of science education is likely to be successful until science is taught effectively in elementary school." At the heart of many of the more effective science teaching programs is inquiry (Anderson & Mitchener, 1994). Inquiry is an activity-based, process-oriented approach to teaching. With this approach, "... intrinsic motivation is more likely to occur" (Hameyer, Akker, Anderson, & Ekholm, 1995, p. 3). An inquiry curriculum can have significant positive effects on student performance (Shymansky, Hedges, & Woodworth, 1990; Shymansky, Kyle, & Alport, 1983; Suchman, 1960; Von Secker & Lissitz, 1999). When compared to students in control classrooms in which comparable content was presented from textbooks, students in inquiry-based classrooms outperformed the control groups in process skills, creativity, attitudes, logical reasoning, and science content knowledge. Improved performance has been found at all grade levels (Bredderman, 1983) with the greatest gains in content and process skills occurring in students who were academically or economically disadvantaged (Bredderman, 1982). The evidence for the benefits of an inquiry curriculum is so strong that the National Science Education Standards (National Research Council, 1996) include explicit recommendations for teaching science as a process and include process as a content area (Content Standard A, Science as Inquiry).

Despite the preponderance of evidence supporting the effectiveness of an activity-based, process-oriented approach to the teaching of science, teachers still rely heavily on the use of textbooks and lectures. The American Association for the Advancement of Science (1990, p.28) concluded that "... conventional science teaching suppresses students' natural curiosity and leaves them with the impression that they are incapable of understanding science," but many teachers continue to have concerns about a process-oriented approach. They believe that the focus on process in inquiry-based curricula goes too far and that too much content is sacrificed; traditional teaching methods are the only way to cover enough material. The perceived minimal content in inquiry-based curricula is not the only concern; what content is included is often not understood by students. Many times, the most interesting hands-on activities are not developmentally appropriate; thus, students are not cognitively ready to understand the concepts that explain activities they enjoy. Under these conditions, student interest cannot be sustained.

Many hands-on activities are just demonstrations in which students handle materials to illustrate concepts. These activities may initially capture students' attention. However, many of the activities are either so highly structured that they minimize exploration or are so loosely structured that they minimize conceptual understanding. To maximize learning, students need opportunities to explore in a way that enhances their understanding.

The Demonstration-Experiment

We have designed a series of inquiry-based classroom activities for the elementary and middle school levels that excite students' curiosity, draw students into the experiences, use simple materials, and explain concepts at developmentally appropriate levels. Our approach addresses teachers' concerns about process versus content and developmental appropriateness (Lynch & Zenchak, 2001; Zenchak & Lynch, 2000b).

The core of our approach to inquiry is the "demonstration-experiment," a structured exploration activity which begins with a discrepant event and then requires the use of scientific inquiry to explain the counterintuitive observations (Lynch & Zenchak, 1995; Lynch & Zenchak, 1997; Lynch & Zenchak, 1999; Lynch & Zenchak, 2001; Zenchak & Lynch, 1996; Zenchak & Lynch, 1998; Zenchak & Lynch, 2000a; Zenchak & Lynch, 2000b; Zenchak, Lynch, & Canlas, 1994). Many scientific concepts can be taught through this approach. For example, "Cannonball" gives students an opportunity to explore conservation of linear momentum at a grade-appropriate level. As illustrated in Figure 1, the teacher sets up two similar situations in which a number of differences (independent variables) have been embedded. Without any explanation, the teacher drops the two balls into the tube in Set-up 1, resulting in the balls staying in the tube. In Set-up 2, the teacher drops the two balls, resulting in the top ball shooting out of the tube. Students are asked to observe carefully what takes place, individually describe in writing what they observe, and compare their descriptions with the descriptions of other students and generate a common list of independent variables and constants. For "Cannonball" the variables are the surface at the base of the tubes (carpet versus hard), the presence of holes in the heavy ball (present versus absent), and the position of the heavy ball relative to the lighter ball (above or below the lighter ball). The constants include the size of the balls, the height from which they are dropped, and the tube into which they are dropped; in addition, the balls are in contact when they are dropped simultaneously into the tube.

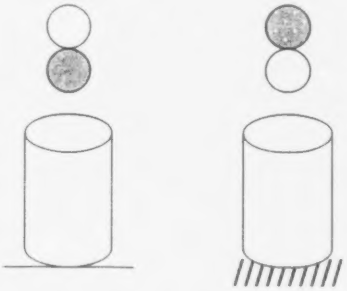

Figure 1. Original set-up for "Cannonball." Variables: Surface at base of tubes, presence of holes in heavy ball, and position of the heavy ball.

Based on the independent variables, the teacher guides the students as they generate a list of hypotheses about what occurred. One hypothesis is generated for each independent variable and takes the form of an "If … then" statement that links the independent variable with the outcome (dependent variable). The teacher repeatedly reminds the students that, in order to identify the reason why the outcome was different between the two situations, they must focus on a single variable while making sure that nothing else changes. In other words, all other variables, except the one in the hypothesis, must be held constant. A hypothesis testing the independent variable surface might be "Holding all other variables constant, if the surface on which the balls are dropped is important, then changing the surface will determine whether one ball shoots out of the tube."

After the hypotheses are formulated, students construct a separate experiment to test each hypothesis. They need to keep the original constants and change the other independent variables into additional constants. Thus, to test the hypothesis that surface is important, students must use one carpeted surface and one hard surface; they might choose to use balls without holes and place the heavy ball on the bottom (see Figure 2). As long as one surface is carpeted and the other is hard, there are three alternative tests of this hypothesis that are equally valid (see Figure 3).

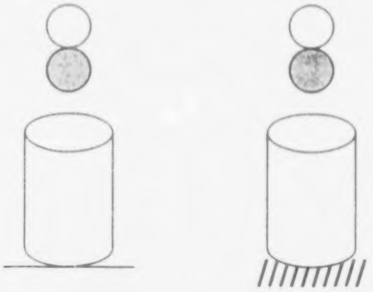

Figure 2. Test of hypothesis that surface is important. Variable: Surface at base of tubes (hard versus carpet). New constants: No holes in heavy ball, heavy ball on bottom.

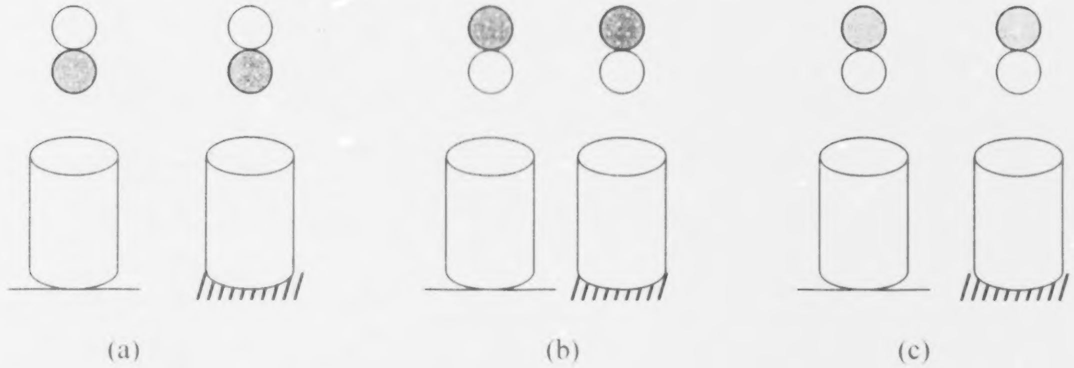

Figure 3. Alternative tests of hypothesis that surface is important. Variable: Surface at base of tubes (hard versus carpet). (a) New constants: Holes in heavy ball, heavy ball on bottom. (b) New constants: Holes in heavy ball, heavy ball on top. (c) New constants: No holes in heavy ball, heavy ball on top.

Next, based on their observations of the initial demonstration, students predict what will happen in each experiment. In the test of the surface variable, students should predict that a ball will shoot out of the tube when the balls are dropped onto the hard surface but not when they are dropped onto a carpeted surface because that is what happened in the initial demonstration. Finally, students conduct all of the experiments they design. They then compare their predictions to the outcomes of the experiments. When their prediction matches the actual outcomes of the experiment, the students know that they have identified the important variable. When their prediction does not match the actual outcomes of the experiment, the students know they can rule out that variable. For "Cannonball" students find that their predictions match the outcomes for the test of the hypothesis about the position of the heavy ball relative to the lighter ball; thus, the position of the heavy ball is the causal variable. After students have identified through their experiments which variable is responsible for the different outcomes, the teacher develops the concepts that explain the results at an age-appropriate level and emphasizes everyday applications.

The demonstration-experiment is unique in a number of ways beyond its combining of discrepant events, inquiry, and structured exploration. First, the situations are deceptively simple. The "equipment" in most demonstration-experiments consists of a few inexpensive common materials that do not necessarily seem "scientific." Because the materials are nonthreatening and do not require training to use, they do not cause teachers and students to doubt their ability to handle them. In fact, the equipment is so simple that nobody expects anything out of the ordinary to take place. However, the demonstration-experiment immediately captures students' attention when small, seemingly inconsequential differences in the two set-ups cause very obvious, yet unexpectedly different results. Second, because the results are unanticipated, the initial differences must be considered in identifying potential causes. Third, students are engaged in the activity because it challenges them to "write the recipe," instead of merely following a cookbook-like approach to finding a solution to the problem presented in the demonstration. They become aware that there are several possible appropriate experiments to test the effect of an independent variable. In turn, teachers are freed to facilitate student inquiry rather than supply them with specific directions and the final answers.

Students are drawn into the experience for two reasons – the two similar situations produce different results, and initially it is not obvious which of the differences embedded in the demonstration-experiment caused the results. Much curiosity is generated and observers immediately start questioning. Through this approach students learn a format for conducting experiments which is structured enough to focus them on the underlying concept, yet loose enough for them to be creative in designing and doing controlled experiments in which only one variable is changed and the others are held constant. Teachers discuss the findings as they relate to the lives of their students. Terminology is minimized to such an extent that it is not seen as the focus and therefore the learner can focus on the underlying concepts.

The demonstration-experiment focuses students on factors which are essential in promoting their understanding of science process and content: the demonstration clearly captures the attention of the students by playing with their minds, not just their senses; it focuses them on variables which may potentially explain what they have just seen; and it prepares them to begin to explore those potential explanations in a format which is structured to encourage both exploration and conceptual understanding.

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AN EXTENDED EXAMINATION OF PRESERVICE ELEMENTARY TEACHERS' SCIENCE TEACHING SELF-EFFICACY

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Strategies for improving science teaching at the elementary level have been the focus of many recent studies. Resultant suggestions include improving science content training, implementing specific science teaching methods courses, moving curriculum in more inquiry and constructivist based directions, and incorporating state and national science standards in classroom. Additionally, researchers have found positive correlations between a variety of productive teacher behaviors and high self-efficacy ratings. These behaviors include increased persistence with students in failure situations, tendencies toward less didactic instructional strategies, higher professional commitment, and a desire to find better ways of teaching. Considerable evidence has appeared that self-efficacy is a predictor of behavior (Tschannen-Moran, Hoy & Hoy, 1998).

Bandura (1977) described self-efficacy as a belief that a person could do something to produce a specific outcome and, second, "a person's estimate that a given behavior will lead to certain outcomes" (p. 79). As with most motivational and attitudinal concepts, self-efficacy is considered to be context specific (Bandura, 1982; Pajares,1996). Thus, to measure teaching self-efficacy, scales need to focus directly on teaching and learning outcomes. In addition, locus of control from Rotter's (1996) social learning theory has been coupled with Bandura's (1977) social cognitive theory to produce a better view of teaching self-efficacy.

Bandura (1986) presents four potential sources that may impact self-efficacy—mastery experiences, physiological and emotional cues, vicarious experiences, and verbal persuasion. Mastery experiences are considered the most powerful source of self-efficacy information, although all may contribute significantly to perceptions of self-efficacy if presented appropriately (see Tschannen-Moran et al., 1998). Research into the application of experiences based on the impact of these sources has demonstrated improvements in self-efficacy in a variety of contexts (Center for Positive Practices, 2000). Applied to preservice teacher training, this research would suggest programs designed with peer modeling by teachers who the students perceive as similar to themselves, opportunities for mastery teaching, verbal persuasion from credible trustworthy sources, and program experiences intended to allow students to be in a positive frame of mind. In an integrated model of teaching self-efficacy (Tschannen-Moran et al., 1998), analysis of the teaching task and assessment of personal teaching competence are both central to teacher perceptions of self-efficacy. Since these are essentially reflective processes, self-reflection skill development is also likely to be necessary in ideal programs.

The original scales designed to determine teaching self-efficacy are based on items measuring respondents' belief about what they are capable of doing (Personal Teaching Efficacy—PTE) and items measuring respondents' belief of what the outcome of their efforts will be (General Teaching Efficacy—GTE). Most current forms of teaching self-efficacy scales are derived from Gibson and Dembo's (1984) Likert scale survey.

Because investigation of self-efficacy makes most sense in terms of perceived abilities related to relatively narrowly define activities (Pajares, 1996), subject matter specific self-efficacy instruments have been developed. A widely used measure specific to science, is the Science Teaching Efficacy Belief Instrument—STEBI (Riggs & Enochs, 1990). This instrument was later adapted to assess science teaching efficacy beliefs in preservice teachers—STEBI B (Enochs & Riggs, 1990).

Even though there has been almost 25 years of research in this area, questions regarding how to measure self-efficacy and what interventions are likely to affect self-efficacy still remain. There is some evidence (Hoy & Woolfolk, 1990) that self-efficacy beliefs can change during preservice teaching experiences but that changes are much harder to effectuate for in-service teachers. Specifically, not much is known about what kind of experiences have the greatest effect and what those effects might be. In general, content area training by itself has not produced increases in science teaching self-efficacy. Methods instruction has shown varied results (Cronin-Jones & Shaw, 1992; Ginns & Watters, 1994). Impacting teaching self-efficacy, however, is problematic because self-efficacy is a construct which develops over time and with experience (Henson, 2001).

Purpose

This study examines the impact of science methods courses, student teaching and science content courses on elementary preservice teachers' science teaching self-efficacy. This research seeks to identify factors that positively impact changes in elementary preservice teachers' teaching self-efficacy beliefs.

Methods

Respondents in this study were elementary preservice teachers in a four-year undergraduate teacher education program. The program is delivered from a School of Education in a small (approximately 2200 undergraduate students) liberal arts private university in an urban setting. Students in this program participate in field experiences each semester of the program. Semesters typically run for 16 weeks. Field experiences in the freshman and sophomore years include about three hours a week in classrooms; the junior year, about six hours per week. During the fall semester of the senior year, students are in classrooms 12 hours a week, and in their spring semester they have a full-time experience. Classroom responsibilities increase throughout the program. Typically, the first two years involve observations, one-on-one tutoring, and small group work. By their junior year, students begin designing and teaching individual lessons. The planning and teaching responsibilities increase greatly in the senior year. During the fall semester, aside from individual content area lessons, the students design and teach at least one 10-lesson unit. In the spring, the seniors have full responsibility for a classroom a minimum of nine weeks during their student teaching experience.

Elementary teachers in the program are required to take nine semester credit hours of science content courses. These courses are Human Biology, Ideas in Physics, and Introductory Earth Science. Most students take these courses in the freshman and sophomore years. These classes include students from other disciplines and are taught by faculty from the respective discipline areas. The content is not specifically designed for education majors and there is no separate lab section with any of the courses. The pedagogy experienced by the students in these science classes varies depending on the individual instructor and course. One instructor employs a rather constructivist approach and incorporates hands-on activities, while another is quite lecture-oriented. The third class tends to be taught by various adjuncts.

In the fall semester of their senior year of this program students are enrolled in a three semester credit hour elementary math and science teaching methods course. The course is designed to integrate theory and practice. Assignments generated in this course are intended to be completed as part of their field experience for the semester (approximately 12 hours per week) and students complete a minimum of one science related teaching experience in their field work. A small number of the students does more science related teaching because they have chosen to design a unit plan focused on a science concept. In the methods course, most pedagogical ideas are modeled with active participation of the students. Students are guided through various inquiry-based science and math activities with specific aspects being discussed during and following the activities. In large and small groups, students discuss their own field classrooms and reflect on the teaching they are doing in their practica.

To measure the students' science teaching self-efficacy belief, students completed the Science Teaching Efficacy Belief Instrument Form B (STEBI B) (Enoch & Riggs, 1990) at the beginning and end of each course included in the study. The science content courses measured met in the fall of 1998 and 1999. During that time period, the education majors sampled numbered five sophomores in Human Biology, 20 mostly sophomores in Ideas in Physics, and 21 freshmen and sophomores in Introductory Earth Science. The methods courses were in the fall of each year from 1997 through 2000. Methods classes had 25, 16, 22, and 35 students respectively. Student teachers were surveyed in the spring of 2001. There were 29 respondents in this group. The students who completed the survey after student teaching in their final semester of the program also reported the number of times during that experience that they had taught a science lesson.

The STEBI-B is a valid, reliable instrument (Enochs & Riggs, 1990) designed for use by preservice teachers. Of the 23 items in the survey 13 are designed to address preservice teachers' level of belief that they can teach science (Personal Science Teaching Efficacy or PSTE) and 10 assess the respondents' belief that their teaching will have a positive effect on the students they are teaching (Science Teaching Outcome Expectancy or STOE). High scores on the PSTE indicate a strong belief in one's ability to teach science. Scores can range from 13 to 65. High scores on the STOE indicate high expectations as regards the outcomes of science teaching. Scores on this scale can range from 10 to 50.

Paired t-tests were run on the pre and post survey scores for each course. The PSTE and STOE section scores were analyzed separately. Since the student teaching experience was contiguous with the methods course the previous semester, the post-test scores from the methods course were used as the pre-test scores for this group. The sample sizes in the content classes were too small for analysis in some cases (n = 5, 11, 21, 9). Accordingly, all of the responses from participants in content classes were grouped together into a larger group (n = 46) for analysis. It is unclear whether self-efficacy scores should be predicted to rise or fall at different stages of pre-service teacher development (Hoy & Woolfolk, 1990). Therefore all analyses of group mean differences were done as two tailed tests. To measure the effect of actual science teaching on self-efficacy scores, the number of science lessons taught during student teaching was correlated with STEBI-B scores.

Results

A total of 399 responses were collected. Of these, 342 had matching pre/post surveys and were suitable for analysis. A number of respondents only completed either the pre or the post, some were completed by individuals who were not part of the study (i.e. non-education majors), and 10 students only completed the front side of the instrument during the pretest. On the post-test for student teachers, 27 of the 29 respondents indicated the number of science lessons they had taught during student teaching.

Means and analysis results for the surveys are presented in Table 1. Analysis of surveys from content classes indicated no significant pre/post shifts on PSTE or STOE scores. Roberts, Henson, Tharp and Moreno (2001) suggest that self-efficacy instruments may suffer from a ceiling effect—that the instrument may not provide sufficient range for respondents who score relatively high initially on the instrument to demonstrate improvement after an intervention. In order to assess the possible influence of a ceiling effect, we followed the lead of Roberts et al., (2001) and ran an additional comparison of the responses from those who scored below 50 on the PSTE portion of the survey for the content courses. This analysis did show a significant increase in PSTE scores (p<.05) but not the STOE scores. However, given the small difference between actual mean scores the practical significance of this finding is questionable.

Significant increases appeared for PSTE in all methods courses (p ranging from <.0001 to <.05). No significant differences occurred in the STOE, with one exception. Significant increases in STOE did appear for the 2000 methods course (p<.05). Again, because of small actual mean differences this does not seem to be of practical significance.

Table 1

Mean Scores for Personal Science Teaching Efficacy (PSTE) and Science Teaching Outcome Expectancy (STOE).

	N	PSTE		STOE	
		Pretest	Posttest	Pretest	Posttest
Content Classes	46	46.77	47.80	34.78	34.76
Low Content	34	44.16	45.85 *	34.12	33.79
Methods 1997	25	46.36	51.12 ***	34.00	34.46
Methods 1998	16	47.19	52.16 **	35.06	34.56
Methods 1999	22	44.50	49.61 ***	33.98	34.45
Methods 2000	35	48.61	52.91 ****	34.16	35.63 *
Student Teaching 2001	28	54.66	55.66	36.28	37.10

Note: * = $p < .05$; ** = $p < .01$; *** = $p < .001$; **** = $p < .0001$

For the student teaching experience, no significant differences appeared. Analysis of the relationship of STEBI-B scores and number of science lessons taught during student teaching shows no correlation exists between the two: the r values were -.09for the PSTE score and .09 for the STOE score. Students reported from 0 to 17 science lessons taught during the student teaching experience.

Discussion

In this study, it would appear that the methods course positively impacted the elementary preservice teachers' PSTE. The scores on this scale significantly increased over the duration of each methods course. The method courses were all taught by the same instructor and, upon reflection, included all of the components identified by Bandura (1986), discussed earlier, that contribute to perceptions of self-efficacy. Mastery experiences were gained through their work in K-12 classrooms. Vicarious experiences were achieved by watching other students teach science lessons in virtual situations, by experiencing the modeling of the course instructor who had considerable K-12 experience, and by observing their cooperating and other teachers at their field school. Social persuasion was delivered by the course instructor, cooperating teachers, and university supervisors with whom the students were working closely. The methods course, coupled with the education program of study, provided the students with a supportive physiological and emotional state. Students had all spent considerable time in K-12 schools before the methods experience and had some weeks with their K-12 cooperating instructors and students before they were required to teach lessons. The students also did group micro-teaching presentations to their college peers in the methods class. These support the likelihood of a more comfortable setting for the students by reducing their initial fears of teaching science in their field placements.

It should be noted that these same students were simultaneously enrolled in a language arts/social studies methods course and an art/music/physical education methods course. Even though the instrument used in this study focuses on science teaching specifically, the fact that students are having multiple similar experiences may indicate that the instrument is actually measuring an improvement in teaching self-efficacy more generally.

At initial glance, it does not appear that taking science content courses affected the students' teaching self-efficacy. By looking only at the students in the content classes who scored below 50 on the PSTE portion on the pretest, a significant improvement in that scale appeared ($p<.05$). It would seem that students with low science teaching self-efficacy may be positively affected by science content classes. Although, given the low practical significance of the group mean differences this must be viewed cautiously.

The student teachers in the final semester of their program did not show significantly higher self-efficacy scores. That group, however, had the highest scores at the pretest of any other group studied. If a ceiling effect does exist, this group would be the least likely to demonstrate improvement. Another possible explanation for a lack of increase is that the student teaching experience did not include the same level of vicarious experience or verbal persuasion as the methods course providing an overall experience less likely to improve self-efficacy. In addition, since self-efficacy had shown a significant increase the previous semester, it would be unusual to expect another significant increase without further intervention.

No group, except the final methods section, demonstrated significantly higher scores on the outcome expectancy portion (STOE) of the post surveys. Concerns over this scale have been voiced by other researchers (Roberts et al., 2001). Most of the instruments designed to measure teaching self-efficacy, including the STEBI-B, share similar interpretations of PTE or what teachers believe themselves capable of doing. How GTE has been interpreted has been more problematic. On the STEBI-B, the STOE scale corresponds to the GTE. Concerns over the GTE focuses on the distinction between expected outcomes being perceptions of what will occur based on how a teacher performs or expected outcomes being perceptions of what will occur based on external influences—the locus of control issue (Pajares, 1996; Tschannen-Moran, Hoy & Hoy, 1998). Riggs , Scharmann, & Enochs (1995) describe the STEBI outcome expectancy items as "reflect[ing] teachers' beliefs in students' ability to learn, given effective teaching" (p. 67). Riggs and Enochs (1990) acknowledge outcome expectancy is a difficult construct to measure because of the myriad of variables it envelopes. While teachers tend to view the construct of PTE rather consistently, teachers view the complexities of the GTE construct with greater variability. As reported in Roberts et al. (2000), only one study has found a difference in the STOE scale of the STEBI-B. Two studies, as noted in Henson (2001), have found a change in the STOE scale of the STEBI-A—the version used with in-service teachers—but this occurred only after interventions lasting 8–12 months. Further study is needed to determine how GTE should be best defined and measured.

Conclusion

Based on the students in this study, it appears that the science teaching self-efficacy of preservice elementary teachers can be improved. An increase in science content does not automatically result in an increase in efficacy. It may be possible, however, that for students whose efficacy is low, an increase in science knowledge may have a positive impact on how they view their abilities to teach science.

For this study, student teaching, in and of itself, did not seem to have any impact on students' self-efficacy. It must be noted, however, that this sample was small and the students already possessed a fairly high sense of self-efficacy. Although some prior research has been done in the area of student teaching and self-efficacy (Hoy & Wolfolk, 1990) this study suggests that additional investigation is warranted.

An encouraging outcome of this study was the finding that methods courses can positively impact preservice teachers' self-efficacy. Previous studies (Cannon, 2001; Wingfield & Ramsey, 1999) have shown that increased time in field classrooms seem to have a positive impact on science teaching self-efficacy. However, while Wingfield & Ramsey (1999) found that methods courses did enhance self-efficacy, Cannon (2001) did not find that methods courses taken in conjunction with field experience enhanced self-efficacy. Although this study supports the position that methods courses do have a positive impact on self-efficacy, it was not designed to investigate how methods courses should be structured and what components of those courses are most likely to impact teaching self-efficacy.

The question of the degree to which elementary methods courses should be integrated among content areas also remains. King & Wiseman (2001) found that integrated teacher preparation courses were no more effective in improving science teaching self-efficacy than pure science method courses. The methods course in this study is an integrated math/science methods course and, for one year, an integrated math/science/art/music/physical education methods course contradicting what King & Wiseman found. Because the course design and delivery of the methods courses in this study were consistent across methods courses we believe this to be encouraging evidence that designing methods courses following Bandura's guidelines related to sources of self-efficacy information is likely to produce methods experiences with greater impact on self-efficacy. Further study is in order.

Because teaching self-efficacy has been shown to be correlated to teaching behavior, continued research on this topic should be continued. Measures of teaching self-efficacy are being improved (Henson, 2001) and measures of outcomes beliefs are receiving appropriate attention. If indeed this section should measure the impact teachers feel they can have on students' learning, we need to be concerned about why these scores are low and typically not changed by what is done in teacher preparation programs. What methods instructors, science content instructors, and teacher preparation programs themselves need to do to encourage positive self-efficacy beliefs in preservice elementary science teachers needs further illumination, including systematic study of individuals as they move through preservice teacher preparation into student teaching and eventually into professional practice.

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A SCIENTIFIC METHOD BASED UPON RESERACH SCIENTISTS' CONCEPTIONS OF SCIENTIFIC INQUIRY

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Within science education, clarifying the definition of inquiry has tended to focus on equipping teachers with methods to teach inquiry (Martin-Hansen, 2002; Colburn, 2000, Lederman, 1998). A key goal of science education reform, however, is to improve student understanding of scientific inquiry and ability to do scientific inquiry (National Research Council, 1996). A significant challenge to providing students with the opportunity to model how scientists do science is the persistent description of the scientific method. The literature contains papers written for teachers that foster a traditional understanding of the scientific method and encourage its use in the classroom (some recent examples include: Nelson, 1988; Haines, 1997; Siebert & McIntosh, 2001; Giunta, 2001). On the other hand, recent criticism of the traditional scientific method model asserts that it is not reflective of how real science is accomplished (Bauer, 1996; McComas, 1996; Lederman, 1998).

Textbooks written for students represent an important vector for the perpetuation of the traditional scientific method (Finley & Pocovi, 2000). The traditional presentation of the scientific method is in the form of a linear checklist leading to the formation of a theory. Taylor (1962) notes that the scientific method has tended to emphasize verification stages rather than science as a creative process. "The core of scientific process is better described by the usual steps in the creative process than by traditional textbooks' descriptions of the specific sequences in the scientific method" (p. 599).

Textbook presentations of science can have a powerful impact on teachers and their students in part because textbooks are often the main resource for teachers and for students to access information about science. Teachers and students naturally assume information in textbooks is an accurate portrayal of science. This provides science textbooks with a powerful influence over how teachers teach science and how students perceive science and scientific practices. If textbooks present science as a static endeavor where investigations invariably lead to theories then students may assume that all scientists conduct science in such a manner.

Gallagher (1991) studied the relationship between textbooks and teachers' perceptions of science. In his study, textbooks tended to describe science as an objective body of knowledge. Similarly, all 25 secondary science teachers adopted the same view of science. Eliot (1989) also expressed concerns that students were primarily getting information about the nature of scientific inquiry only from lectures and textbooks.

The Biological Sciences Curriculum Study (BSCS, 1963) voiced their concern over textbooks that tended to treat biology as stable facts without the human side of scientific investigations. Schwab (1962) also expressed concern with textbooks portraying science as consisting of "empirical, literal, and irrevocable truths." This portrayal of science in the textbooks did not match the changing perceptions of the accumulation of scientific knowledge. Scientists' views of scientific knowledge had shifted from a deterministic mindset where scientific laws and theories were either proven or disproved to a mindset where knowledge is probabilistic and laws and theories are subject to revision as new evidence is considered. Thus, "the knowledge won through enquiry is not knowledge merely of the facts but of the facts interpreted" (Schwab, p. 14).

For students to develop a more realistic picture of how scientists practice science, there must be a well-researched understanding of how scientists do science. A model for the process of scientific inquiry that more closely reflects actual scientific practices can provide a means of dispelling some of the myths about scientific inquiry. This paper presents an analysis of the presentation of the scientific method that is in a group of current science textbooks. Combined with this analysis are new results from a separate study of research scientists' conception of scientific inquiry (Harwood, Reiff, and Phillipson, submitted). From these results, we have developed a new model for the process of scientific inquiry that we call the "inquiry wheel." In this paper, we compare and contrast the traditional scientific method with the model of the inquiry wheel.

Methodology

In the textbook analysis phase of the investigation, we examined the scientific method presented in 40 randomly selected science textbooks reflecting science at various grade levels and subject areas. The textbooks used in our study consisted of twenty biology books, five earth science books, five chemistry, five physics, and five lower grade level science books. In each of the textbooks, accounts of the scientific method were analyzed with respect to the steps listed and the number and type of "feedback loops". These loops represent some effort by the textbook authors to be less linear (step-wise) in their presentation, a key criticism in the literature. The publication dates of the textbooks ranged from 1989 to 2000. While the scientific method may have been portrayed differently in earlier versions, we are primarily interested in the scientific method to which students are currently exposed.

What we will describe as the "inquiry wheel" emerged from an earlier study conducted with 52 science faculty members from nine departments (anthropology, biology, chemistry, geography, geology, kinesthesiology, medical sciences, physics, and environmental science) at a large Midwestern University (Harwood, Reiff, & Phillipson, submitted). The semi-structured interview protocol was designed to probe the subject's conceptions of scientific inquiry. Interviews were tape-recorded and interviewers took field notes during the interview.

As part of the investigation into scientists' conceptions of scientific inquiry, scientists would often describe how they did science. Key questions in the interview protocol that provided pertinent information included,

- What is scientific inquiry?
- What are some characteristics of scientific inquiry?
- Can you think of an experience that involves scientific inquiry?

Scientists highlighted important characteristics of an investigator, an investigation, and how they practiced science (Harwood et al., submitted). From reading transcripts of the 52 interviews, it quickly became clear that scientists practiced science in ways not depicted in common science textbooks. Moreover, several scientists spontaneously provided strong criticism of the traditional scientific method and made direct contrasts between the scientific method and their perspective of the process of scientific inquiry. The inquiry wheel emerged from the analysis of the collection of scientists' descriptions regarding how they practice science.

We explored the similarities and difference between the textbook (traditional) version of the scientific method and the inquiry wheel using a grid that listed each of the stages of the inquiry wheel. When a term described in either the text or the model matched the stage on the inquiry wheel, this was recorded. For example, in virtually every case, each textbook listed the step: forming a hypothesis. We identified "forming a hypothesis" as corresponding to the inquiry wheel's stage *articulating an expectation*, thus identifying a common feature.

Analysis of Textbooks

The scientific models presented in the textbooks closely resembled the versions of the scientific method that was widely criticized in the 1960s (for example: Schwab, 1962; Taylor, 1962). Much of the writing of the 1960s criticized an earlier portrayal of the scientific method as a five or six step process that leads directly to conclusions of science problems. These steps include: 1) defining the problem, 2) constructing the hypotheses, 3) experimenting, 4) Compiling the results, and 5) Drawing conclusions (National Society for the Study of Education, 1947).

Many of these steps outlined in the first half of the twentieth century persist in modern science textbooks. Finley & Pocovi (2000) identify six steps to the scientific method as:

1. Recognize and research the problem
2. Form a hypothesis—a statement that can be tested.
3. Conduct an experiment in which you control variables to test the hypothesis
4. Collect, organize, and analyze all relevant data.
5. Form your conclusions—which may lead to another hypothesis.
6. Present the theory…a hypothesis that has been tested again and again by many scientists with similar results each time.

This version is very similar to those found in the textbooks we analyzed. Uniformly, the scientific method conveyed by the textbooks portrayed this sort of stepwise, linear process for doing science. The result of these steps in many cases was a theory or scientific law when, in fact, many scientific studies do not result in the formation of a law or theory (Lederman, 1998). Thus, these models of the scientific method perpetuate the misconceptions that scientific achievements occur through following a predetermined path, and that science invariably leads to a theory.

Interestingly, we found contradictions between the text and figures depicting the scientific method. Most textbooks had a discussion in the text that reinforced the view of the scientific method as a procedural set of linear steps describing the process of scientific inquiry. In several instances, however, the text accompanying the figure described how the scientific method did not follow steps in a particular order. Yet, when the figure was presented, it typically depicted the scientific method in a linear way with few feedback loops connecting to previous steps. We explored the "linearity" of the scientific method by associating the number of feedback loops with the amount of linearity. Greater numbers of feedback loops were presumed to indicate lower linearity. Thus, textbooks depicting the scientific method with no feedback loops are linear. Some textbooks showed one or two feedback loops, which is a less linear depiction of the scientific method. The least linear depiction occurred in one textbook that showed four feedback loops.

Chemistry textbooks had the highest frequency of feedback loops represented in models of the scientific method. In addition, chemistry textbooks had the highest number of figures depicting the scientific method than any other science discipline surveyed. Four out of five chemistry textbooks contained figures depicting the scientific method with between one and three feedback loops. In spite of these feedback loops, the chemistry textbooks still portrayed a linear, stepwise process to conducting scientific inquiry. Although one text did include the statement, "Just because results look neat and tidy does not mean that scientific progress is smooth."

Biology textbooks contained a wider range of feedback loops. Three depictions of the scientific method contained zero feedback loops, four depictions had one feedback loop, one depiction had two feedback loops, and one depiction had three feedback loops. In one textbook, the scientific method was presented as a cycle with arrows pointing in a one- way direction to the next step. Though the cycle represented another visual image of the scientific method, the one-way arrows indicated that steps were not repeated and, thus, was identified as having no feedback loops. Eleven of the twenty biology books did not even include a depiction of the scientific method. This may have been a conscious effort to avoid presenting a representation of scientific inquiry that did not represent the actual practices of science.

One biology textbook stated when referring to the scientific method, "few scientists adhere to these rigid steps." This contrasts with the more typical statement from another biology textbook that described the scientific method as "involving a series of ordered steps and is a tool used by all successful scientists." Like the chemistry textbooks, however, the figures of the scientific method clearly represent a smooth stepwise procedure.

Two of the five earth science textbooks contained depictions of the scientific method. In both of these cases no feedback loops were present. One of the earth science textbooks stated that the steps of the scientific method do not follow in a particular order. "They are not sequential steps that scientists invariably study. They are guides to problem solving." However, the earth science depictions of the scientific method did not demonstrate this flexibility.

In many of the physics textbooks surveyed, the scientific method was not mentioned in the text nor was it depicted with a figure. Only one of the five physics textbooks contained a depiction of the scientific method and this contained no feedback loops. This physics textbook introduced the scientific method with the statement, "This simple, step by step chart is easy to understand, but, in reality, most scientific work is not so easily separated." Yet the depiction found in the book contradicts this statement in the text.

In the science for lower grades textbooks, two out of five textbooks contained depictions of the scientific method. As in the biology example, one of the middle school textbooks had a cycle with one directional arrow, representing zero feedback loops. In the other depiction, four feedback loops were present. This is the only one of the 40 textbooks surveyed that had so many loops in the depiction of the scientific method. The low frequency in number feedback loops found in other 39 textbooks indicates that the image of the scientific method as a linear series of steps is still strongly present in modern science textbooks.

Among the 40 science textbooks we analyzed, the most common descriptions of the scientific method across all science disciplines included steps for constructing hypotheses and experimenting. The least frequent steps mentioned across all disciplines in models of the scientific method or in descriptions of the scientific method in the text include reflecting of the findings and communicating the results to society. Recent work by White and Frederiksen (1998) indicates the importance of reflection. In their model, however, the scientific method is depicted as a cycle with no feedback loops.

Scientists' Perspective of the "Scientific Method"

The research scientists who were interviewed in our study (Harwood, et. al., submitted) had strong opinions about how the scientific method is portrayed not only in textbooks but also in the classroom.

> The thing that happens in high school is they try to force their science project into the scientific method. You must have a hypothesis and make your predictions. It's absolute gibberish. Before you have given me information, you are trying to make me guess. That doesn't make sense. That's not science. The answer is—you have to have a question.

A biologist comments, "Children start out as scientists. We beat it out of them. Most people start out as curious. Somehow that curiosity disappears over time."

The scientists in our study consistently described the iterative nature of conducting science. Progress in science is not linear with few opportunities to repeat previous steps but rather a dynamic process where questions and results contradictory to expectations are also valued. A biologists in our study commented that the process of science "is rarely that neat. It's usually a much messier process." In a similar vein, an anthropologist says the following about the traditional scientific method:

> Now will they always follow along a scientific protocol or step-by-step methodology? I don't think so but then science doesn't either. Hypothesis, methodology, testing results, conclusions. Things don't move around in quite that progression.

The Model of the Inquiry Wheel

Scientists frame the process of their work within the context of methods that are nonlinear. This has forced us to develop a more sophisticated model of the process of scientific inquiry than the traditional scientific method previously discussed. We frame the inquiry wheel as having questions at the hub and a cyclical arrangement of stages that are typically used by investigators as they pursue a line of inquiry (Figure 1). The importance of questions is noted in a geologist's statement:

> Every time when you ask a question, it should lead you to another question, which ultimately creates knowledge. Questions provide the transition that has to be made as you build your knowledge.

For our subjects, the inquiry wheel can be viewed as a set of stages that provide responses to questions and generate new questions. These questions and their answers are the force that moves the investigation forward. In this model, scientists have the flexibility to generate questions along each stage and to revisit previous stages whenever needed. This fluid approach is indicated by double-headed arrows on the figure and better portrays how science is practiced among scientists than the standard "check-list" found in textbooks.

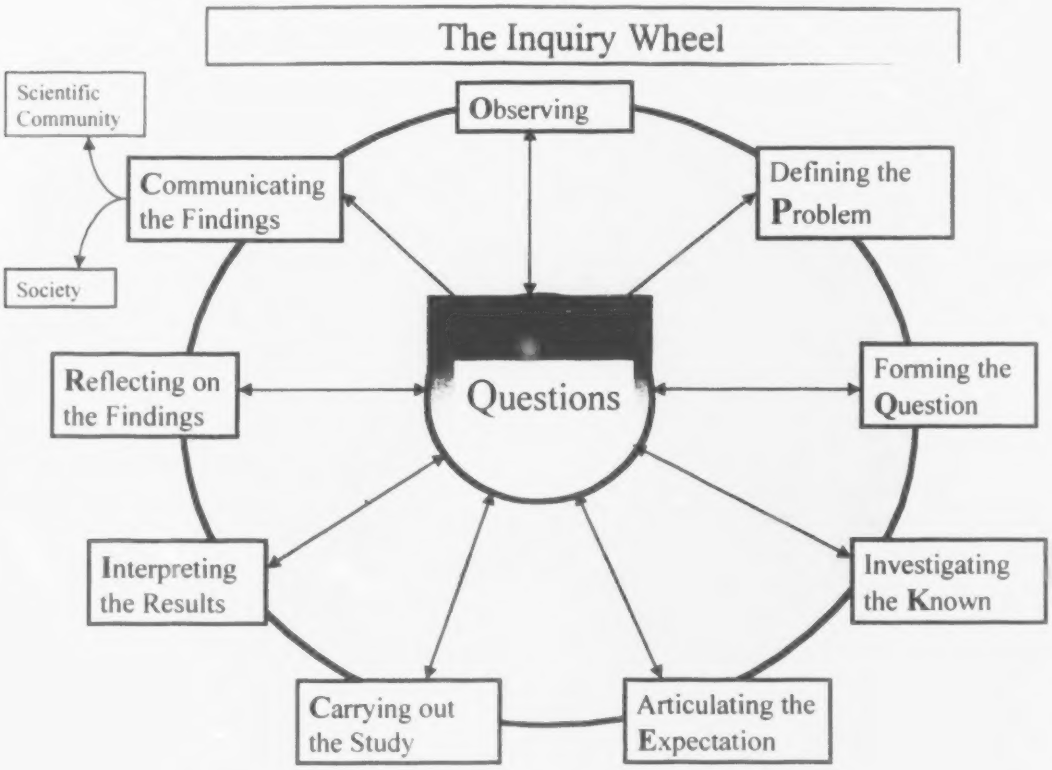
The Inquiry Wheel
Scientific Community
Observing
Defining the Problem
Communicating the Findings
Society
Questions
Reflecting on the Findings
Forming the Question
Interpreting the Results
Investigating the Known
Carrying out the Study
Articulating the Expectation

Figure 1: A proposed method of inquiry

Indeed, it needs to be emphasized that the inquiry wheel is not an *inquiry cycle*. That is, a circular set of steps such as that provided by White & Frederiksen (1998). A more related model is that provided by Krajcik et al. (1998 and 2000) as the inquiry web, which depicts the process of inquiry as going in many directions and by many paths.

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In the conception of the process of scientific inquiry that emerged from our study, scientists may begin an inquiry investigation anywhere along the wheel. Even in the communicating the findings stage, questions posed by the scientific community could prompt another investigation. Moreover, scientists described the process of repeating stages as an important part of process of scientific inquiry. Communication, for example, occurs throughout a study in both formal and informal ways that inform the scientist and improve their ability to complete their inquiry. The inquiry wheel shows the dynamic nature of scientists repeating previous steps and generating questions during an investigation. The stages of the inquiry wheel are each outlined below. For those stages with equivalent sorts of items in the traditional scientific method, we include a brief comparison between the stage and the method step.

Making Observations

Observations occur throughout the entire inquiry wheel. Observations are essential in keeping careful records, staying focused, and serving as a springboard for the development of questions. Questions may arise from observations using the senses, reading in the literature, or from the scientist's sense of curiosity. A geologist explains the importance of observations in his field,

> Well, in our case observational skills are part of the key. Many people look but they do not see. The fundamental skill in our science for starting the inquiry process is to look and to see.

An anthropologist described how he helped students develop their observational skills by asking them, "Tell me what you see, tell me what you hear, tell me what you feel, tell me what you are observing or holding or whatever." These observations can move an investigation to another stage or serve as an instigation to begin an investigation. The latter can come about because the investigator may notice, through observation, that there is a strange or interesting occurrence. If nothing else, this may give rise to the question "what is going on here?" that can serve as the starting question of an inquiry.

Defining the Problem

Scientists define a problem based on their observations and their understanding of the literature. They must be able to decide from the observations what problems are testable, falsifiable, and that contribute to the scientific knowledge base. The ability to define a problem capable of resolution and one that's worth investigating requires a lot of work. Some scientists considered defining a problem as a natural aptitude while other scientists considered that "anybody can learn how to choose a problem and a methodology that works."

Forming the Question

While defining a problem may occur after a question arises, it appears to be more common that a problem statement is turned into a question to serve as the focus of the investigation. Articulating a question, however, can be challenging. A geologist explains, "The hardest thing to teach is the ability to ask the right questions." The importance of forming questions cannot be overstated.

> Inquiry is forming a new question. I think that what part of that means is not always having students ask questions, but having them understand that the way that information came about was through asking questions. Even if students aren't designing a new question, they still should understand that information is the result of an inquiry-based kind of process.

Questions are a natural result of curiosity that lead us toward new knowledge and new understanding. As an anthropologist observed, "not knowing is what stimulates inquiry." Questions, then, are the driving force of a scientific inquiry.

In the science textbooks the step of forming a question tended to be a result of turning a defining statement into a question. In our inquiry wheel this may also be the case, but a different order of events is also possible. One could start with a question and then define the problem and refine (if necessary) the question. Other stages could also be inserted between this sort of iterative sequence of events through two stages of scientific inquiry.

Investigating the Known

At this stage, scientists may be unsure if others have found an answer to the question under investigation. Moreover, there may be information available that will guide the study to a fruitful conclusion. Scientists gather information related to the question from reading the literature or by talking with experts in the field. The latter is one example of *Communication* occurring at an early stage in the inquiry process. This represents a contrast to the textbook scientific method where communication, when it is mentioned as a step, only refers to reporting at the end of an investigation.

Investigating the known allows scientists to define the boundary between what is already known and what is unknown about the topic. A medical scientist described this process as moving from "the certainty to uncertainty." A high value is placed on seeking answers to questions that address unknown areas in science and, therefore, have the potential to extend our understanding.

> This, of course, very much depends on knowing what is known, and most of science is simply keeping track of where the knowledge base is. Who knows what, and so a lot of what you see in scientific writing is review. That's for the reader to know that you what you claim to know. I think scientific review, literature review if you will, is the test of your credentials because a good reviewer will be able to detect whether you are that border, whether you are going to contribute anything beyond what is already known.

True scientific inquiry was described as an accumulative process in which new questions are asked that contribute beyond what is already known. This information gathering stage may result in the investigator gaining an answer to the original question, the question may be modified to address an issue that is not yet known, or the investigation can continue to verify known results. Informed by a deeper understanding of the topic, the investigation may proceed to the next stage.

Articulating the Expectation

The information-gathering stage just completed provides material that may take the scientist back to stages we have already described to further refine or change the problem or question. A good understanding of the literature around the topic of interest also guides the scientist in developing a preliminary (unproven) answer to their question. Common forms that these preliminary answers take are a hypothesis or a prediction. Broadly, the scientist articulates an expectation for the outcome of the investigation. This may be either a formal or informal articulation.

In the science textbooks surveyed, "forming a hypothesis" is equated with this stage of the inquiry wheel. Several science textbooks defined a hypothesis as an "educated guess". Other textbooks defined hypothesis as a "possible solution to a problem" or "a statement that can be tested." A biologist in our study found this fixation on hypothesis formation limiting as well as frustrating.

> But the way that many of the textbooks force people to teach and the way my son was taught in schools to say you must have a hypothesis. You must write down your predictions. For any kinds of information that makes no sense whatsoever and kinds are turned off. They are told this is how you do scientific inquiry, but it is not. It's true for some kinds of things. But for all the kinds of stuff we do, it doesn't work that way. Why are you telling me to guess an answer before I have done anything? Before you have given me information you're trying to make me guess? That doesn't make sense. That's not science.

Carrying out the Study

Based on the literature study and the expected direction for an answer, scientists begin planning and designing the investigation. That is, they seek an evidence-based answer to the investigative question. Scientists use multiple methods or approaches to investigate their question. The scientist decides which method will be appropriate for the investigation and then selects tools that will assist in conducting the method for the study.

> Having an awareness of a given field and a background is critical to pose new scientific questions. Then I think there has to be some kind of plan of action of how you're actually going to address that question.

To gather evidence, the investigation may take the form of an experiment or a test, though other designs are also used. In instances of an experiment or a test, scientists will control variables and manipulate one variable at a time to study what is causing the problem. In other cases, such as discovery research (Lederman, 1998), scientists may make no effort to control the events in a given setting. Their choice of tools and setting, however, are influenced by their expectation that these will provide useful responses to their question.

Interpreting the Results

After data have been generated from carrying out the study, scientists examine what the results *say*. Data can take the form of measurements, field notes, observations, statistical analysis, surveys, etc., depending on the method chosen to gather data. Regardless, the scientist looks for patterns and connections within the data. If the data is inconsistent or some error has appears to have occurred in gathering the data, the scientists may decide to repeat some of the previous stages. This may lead the scientist to revising the method, refining the question, researching more information about the topic, or making additional observations. The fluid nature of the inquiry wheel conveys the natural process of repeating stages to arrive at sound results.

Some students may think they have finished an investigation when they have completed the data gathering stage. For some scientists, this is where science really begins. One scientist explains, "I think too many people think science is collecting data in the lab. What I tell my students is that science begins after you have collected the data." The final stages of checking procedures, going back to the literature, synthesizing data, taking a step back from the data, sharing results are places where meaningful discoveries can be made.

Reflecting on the Findings

Unlike the interpretation stage where findings deal with what the results *say*, reflecting on the findings determines what the results *mean*. In trying to find significance in the data, scientists spend many hours looking for patterns in the data and making connections to the known information. One scientist explained, "…the most underrated part of research is thinking. So you just think about it with a pencil and paper and reading some very, very basic books."

Several scientists described how the best scientists such as Einstein and Newton were able to see connections where no one else saw them. In Harwood, et. al (submitted), the most important characteristic of a scientist was the ability to make connections between the data. That is, to be able to focus on the details of an investigation but also to see the larger picture.

Some scientists reported that they spent time reflecting on the meaning and implications of their results at odd hours or locations. Theses "flashes of insight" or serendipitous moments can occur outside of the laboratory. At these moments, scientists take a step back from the data and make connections. To some scientists, the reflection stage is the most underrated part of an investigation.

> The interesting experiments are always serendipity, I think. They come in the middle of doing something. If you aren't doing anything, you can't make discoveries.

Almost all of the science textbooks (38 out of 40) made no mention, either in the text or in the depictions of the scientific method, of reflection as an important part of an investigation. This is the key modification to the traditional scientific method that is provided by White and Frederiksen (2000).

Communicating the Results

"If information is not shared with others then it may as well not have existed." This is the opinion expressed by a scientist who stressed the necessity of communicating findings to both the scientific community and to the public. Scientists stressed the importance of having good communication skills to explain to others findings in written and oral form. Communication often generates new ideas in the process of bringing ideas together and responding to inquiries.

It is important to note again that communication does not just happen at the end of an investigation. Scientists described how they collaborated with other scientists throughout the investigation.

> I think it's helpful to have people to bounce ideas off of. I mean you tend to get set in your own way of thinking and don't consider other possibilities and just by discussing things with other people you can see other alternatives.

In addition, there are several audiences for the final communication from a scientific inquiry. First is communication to peers in the scientific community. This is essential in verifying the results for validity and reliability purposes and for career advancement opportunities.

A second, and also important, audience for scientific information is the general public. The gap in the public's perceptions of science and how to obtain scientifically valid information concerned some scientists. A geologist explains,

> You could easily fool the public into really weird opinions. When you talk of chemical, everybody is scared. Everything is a chemical so that's ridiculous.

Communicating findings to the public can benefit society by increasing awareness about scientific issues, helping people make informed decisions, alleviating fears about science, and encouraging questions about everyday problems.

Though the science textbooks surveyed included communicating findings as a step in the scientific method, communication referred almost exclusively to the scientific community. Only three textbooks out of 40 mentioned sharing findings with the rest of the class or with the public. All three references to communicating scientific information with the public occurred in biology textbooks.

Questions

The inquiry wheel is again refueled by questions that spark another investigation. The cycle continues as more questions are fed into the system. One scientist described the central role of questions as:

> You should question everything. Question, question, question. Why, why, why? If nothing else, science is important for that. It keeps everybody on his or her toes. If there were more scientists, we would be on our toes. We are not on our toes.

Inquiries lead to the building blocks of knowledge. How the blocks are constructed depends on the person or society constructing the knowledge.

Conclusion

The traditional textbook depiction of the scientific method as a linear process fails to accurately portray the lively process that scientists use in approaching their scientific inquiries. Moreover, the scientific method provides a set of steps that are procedural and omit important parts of the inquiry process such as reflection.

The inquiry wheel presented here is a theoretical construct that emerges from a grounded theory-based research project examining scientists' conceptions of scientific inquiry. Because of the strong research basis, the inquiry wheel provides a more sophisticated and more authentic model of the process of scientific inquiry. Textbooks typically provide a set of five or six steps as the scientific method with little or no indication of any opportunity to return to earlier steps. In contrast, the inquiry wheel has nine stages with double pointed arrows allowing unlimited opportunity to go back and forth among the stages as often as necessary. In textbooks, the end product of the scientific method is usually a theory or law. In the inquiry wheel, however, the end result is not a theory but the chance to drive another investigation through questions. This dynamic model emerged from interviewing 52 science faculty members who described how they practiced science.

It remains to be seen, for example, what impact the use of this model will have on teacher belief and practice or on student learning of science. A limitation of our model is that it emerged from scientists' beliefs about what they do. It may be that scientists do not actually conduct their research inquiries as they believe. Thus, additional work to connect our model to scientists' actual research practices needs to be carried out. Even so, our model legitimately reflects the ideal of scientific inquiry expressed by active research scientists from a variety of disciplines. As such, it represents a set of stages that students of science should be encouraged to note and use during classroom based science inquiries. The inquiry wheel provides student with clear model for doing science as scientists do and one that is much more comprehensive than the traditional scientific method.

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WE TEACH AS WE WERE TAUGHT: INTEGRATING ACTIVE LEARNING AND PEDAGOGY INTO UNDERGRADUATE SCIENCE COURSES

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A clear call was made to increase scientific literacy for all Americans (American Association for the Advancement of Science, 1990; National Research Council, 1996), yet most K-12 teachers and university professors continue to teach science in the same, traditional way they were taught. Scientific literacy remains low and attitudes toward science are poor. Science education at the elementary level appears to be following the dinosaurs into extinction. There are many reasons for this, but one of the on-going problems is the lack of science content knowledge and, therefore, lack of confidence in teaching science by elementary teachers. Many universities require only eight semester hours of science for students entering a teacher education program. Once in the program, most universities offer one course in science methods, focusing on pedagogy, not science content. The problem is greater than just the limited number of courses, however.

Courses need to be developed and modified to: (a) make science accessible, (b) build on national science standards, (c) form real-life connections, (d) demonstrate cultural inclusiveness, and (e) blend pedagogy with content in order for pre-service teachers to see the value of undergraduate science courses.

This paper details the on-going project by a team of faculty from multiple departments at a large urban university and a large urban community college to infuse pedagogy, cultural literacy, active learning,, and virtual field experiences into science courses for undergraduates who have indicated an interest in teaching. The participating university has historically educated the vast majority of teachers in the region (recommending more than 30,000 for credentials in the past 25 years) and the majority of transfer students come from the collaborating community college. The primary goals are to provide the students, early in their college careers, with a greater understanding of scientific concepts, a recognition of the relevance of science to a career in education, and a model of science teaching using innovative teaching techniques.

Teacher Education Programs

Preparing knowledgeable teachers requires carefully developed coursework and field experiences in content areas to model good instruction and to link theory and practice. Retention of teachers, especially in urban areas, is dependent on quality and realistic preparation. There is strong evidence that understanding the complex nature of teaching requires significant time and reflection, which suggests shortcomings in California's fifth-year (9 month) credential programs. Mertz and McNeely (1991) found constructs believed by prospective teachers about the nature of teaching were strongly held and deeply imbedded, even in instances in which the ideas were mutually exclusive. Many times, these beliefs constrain the development and learning which can occur in a teacher education program. The beliefs are deep enough, in fact, that Gormley (1991) found prospective teachers only just began to understand and value the relevancy of education courses as they were finishing the preparation program.

Adding to the problem, elementary teachers seem to remember little of the science content from their undergraduate courses, have minimal enthusiasm for science, and do not recognize the relevancy of science to elementary teaching. The project described includes courses built upon educational research pointing to the crucial role of active participation by the student in his or her learning process (Bransford & Vye, 1989; Gallimore & Tharp, 1988; Resnick, 1983). Although the format of laboratory courses inherently offers the opportunity for "active learning," many of the traditional experiences are criticized as "hands-on" but not "minds-on" (Gallagher & Reid, 1981). A similar shortcoming has been the minimal assimilation of facts and concepts into an integrated whole. This fragmented acquisition of knowledge leads to misconceptions and lack of retention, but can be overcome when integrative and critical thinking activities are incorporated into the curriculum (Zohar, Weinberger & Tamir, 1994).

Cultural Literacy

A vital component of the new course described in this paper is the infusion of cultural literacy. Based on 1998-99 county demographic enrollments (American Indian 0.9%, Asian

4.9%, Pacific Islander/Filipino 5.8%, Hispanic 35.7%, African American 8.7%,White 43.8% - Source: California Department of Education, Educational Demographics Unit – CBEDS), the majority of elementary school children in the county in which this project is situated are ethnic minority and within five years, more than 50% will be English Language Learners (ELL). In many urban schools, half of all beginning teachers leave teaching permanently after only three years in the classroom. Among under-prepared teachers, the attrition rate doubles (California Commission on Teacher Credentialing, 1997). In the largest district in this county some schools with low-income, high ethnic minority populations have a teacher attrition rate of nearly 35% per year.

In a study by Hynes and Socoski (1991), prospective teachers demonstrated naïve and erroneous attitudes toward urban teaching. They believed teachers needed *less* content knowledge to teach in an urban setting. These naïve beliefs are compounded by a lack of personal experience and knowledge of urban settings. Where direct knowledge is lacking, stereotypes, fear and suspicion take over, influencing assumptions that teachers make about their students (Dusek & Joseph, 1983; Weinstein & Soule, 1991). Teachers in these schools have few experienced role models. Virtual field experiences, modeling excellent elementary science teaching in urban schools, and the infusion of cultural literacy in content courses throughout the college career of prospective teachers should help to alleviate some of the challenges.

The New Course

The new course included a variety of activities and lessons which differed from the traditional general biology course, although the bulk of the content was the same and the course number remained as before. Interactive techniques such as pair-share, study teams, active simulations, and scientific current events were introduced into the lecture course. Students had assignments including reviewing the state science content standards to identify biology topics, viewing videos of children learning biology, analyzing biology lesson plans, examining their own writing and drawing for cultural biases, and preparing small group presentations. These assignments, although centered on traditional biology topics, were different than those completed by students in the other sections of general biology.

Results

The results from this preliminary work suggest it is possible to make changes in students' attitudes about science, their views of the importance of science to elementary teachers, and their understanding of the nature of science without "diluting" the content. In interviews, students reported that reviewing activities designed for elementary students helped them understand the content even if they weren't going to continue on to become teachers. Students remarked on how much children were able to understand about scientific concepts if they were taught "the right way." Students reported becoming more scientifically literate. One student's response to the question "Is there bias in science?" was: "When we say that science is not without bias, we mean that different conclusions often can be derived from the same results. Science is not immune to prejudice by scientists because they are human. Prevailing beliefs of the time have a direct effect on the interpretation of science. Although scientists do their best to evaluate data impartially- who they are- how they are raised, etc., plays a part in how they see things and interpret data." These responses differed markedly from responses in other sections of general biology.

Students were interviewed regarding instructional strategies that were implemented in this class. Several themes emerged, indicating students (a) greatly benefit from "stories" connecting real-life with science topics, (b) strongly believe there should be multiple assessment methods, (c) respond positively to pedagogical examples that support conceptual understanding, (d) believe the topics in general biology were appropriate, but there was too much detail, and (e) strongly believe lecture should be more interactive.

We believe teachers teach the way they were taught. Therefore, it is imperative that future teachers enroll in science courses early in their college careers that model excellence in teaching. These courses must utilize strategies and materials shown to be effective and must help future teachers to understand the cultures among which they are likely to teach.

Significance

This work is important for science educators because it presents a model to begin to infuse cultural literacy, pedagogy, and virtual field experiences into general science courses early in the college career of potential educators. It addresses, although does not yet solve, major challenges in the current elementary teacher education system regarding the lack of science content knowledge, limited experience with cultural issues in science, poorly modeled science teaching, and a paucity of elementary science field experiences. The project involves collaboration among teacher educators, science faculty, and elementary school and has the potential to directly influence the education of over 600 future teachers annually.

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TEACHING CONTROVERSIAL ISSUES OF BIOETHICS

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The Need for Controversial Issues in the Curriculum

Leaders of science education have urged that high-school students should be involved in dealing with the controversial issues arising from such topics as genetically engineered foods. The following quotations support the inclusion of current issues in the high-school curriculum:

The National Academy of Sciences in the *National Science Education Standards* (1996, p. 190) observed:

> The relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science. . . . Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world (p. 193). . . . There is some research supporting the idea that S-T-S (science, technology, and society) curriculum helps improve student understanding of various aspects of science- and technology-related societal challenges (p. 197).

AAAS (1993, p. 186) in *Benchmarks for Science Literacy* recommended that

> by the end of the 12th grade, students should know that new varieties of farm plants and animals have been engineered by manipulating their genetic instructions to produce new characteristics. . . Biotechnology has contributed to health improvements in many ways, but its cost and application have led to a variety of controversial social and ethical issues (p. 207).

Many teachers avoid controversial topics because they do not want to upset students or parents, do not know appropriate instructional strategies, and fail to recognize the importance of motivating students through placing science in its relevant context. The following example is used in a methods course for helping future high-school teachers to use an instructional strategy that involves their students in active participation in understanding an important controversial and current topic.

Importance of the Controversial Issue in Biotechnology

During the year 2000, $36.8 billion was invested by Wall Street as new capital in biotechnology industries (Abate, 2001). After leading Wall Street during much of 2000, biotech stocks have slipped 14 percent so far in January, 2001. J. P. Morgan investment banking Chief Executive Officer Dan Case predicted that the biotech outlook for 2001 will be "down from 2000 but not as bad as the bears expect."

The Human Genome Project, completed in 2000, was the most expensive scientific project ever attempted. It encouraged the rapid growth of investments in biotechnology industries promising to provide new gene-based medicines. Simultaneously it has led to a host of ethical dilemmas, including individual rights to privacy about their genetic conditions. Francis Collins, chief of the U. S. Human Genome Project, conceded that nobody has come close to solving the ethical and practical aspects of the genome puzzle (Hall, 1999). Various ethical problems can threaten the existence of biotechnology industries because the public could demand the elimination of procedures necessary for these industries.

Products of the biotechnology industries involve the procedure of gene splicing. Some Americans oppose any use of this basic procedure. In 1995, Richard Land, head of the Christian Life Commission of the Southern Baptist Convention said:

> This issue [of genetic engineering] is going to dwarf the pro-life debate within a few years. I think we're on the threshold of mind-bending debates about the nature of human life and animal life. We see altering life forms, creating new life forms, as a revolt against the sovereignty of God and an attempt to be God (Andrews, 1995).

Jeremy Rifkin, president of the Foundation on Economic Trends, has applied for a patent for cloning animals that carry human genes. His goal is to block others from using procedures that could produce a chimera, i.e., a partly human new subspecies providing parts and chemicals useful to medical procedures. Already chimeras exist; animals have been genetically engineered to carry human genes for making products ranging from lactoferrin that can boost the immune system, to alpha anti-trypsin for treating cystic fibrosis. Rifkin and his followers oppose the claiming of a human embryo as intellectual property (Reuters, 1998).

Topic for Jig-Saw Lesson: Genetically Engineered Foods

The *San Francisco Chronicle* reported that Donald Kennedy, editor in chief of *Science* magazine, former president of Stanford University said:

> I think there are three kinds of opposition to the whole area called genetic engineering, and to genetically modified foods and genetically modified organisms for the production of non-food products. One of the concerns is environmental risk, and some that is reasonable and some of it still needs to be evaluated. The second is worry about unforeseen and unknown impacts of introduced substances in food -- and to the extent that people are worried about possible allergens, that has a limited domain of concern. The third is that somehow these methods intervene in an unnatural way in a process that ought not to be intruded upon. A lot of people wouldn't describe that third concern in the same way, I think, but they nevertheless feel it, even if subconsciously. I really don't know what to feel about that (Pearlman, 2000, p. A6).

A handout (provided to participants in the demonstration) presents abstracts from many other articles that give examples of each of the three issues identified by Dr. Kennedy. Participants are invited to deal with these issues to arrive at their own ethical conclusions by use of an instructional technique called Jigsaw. It is an instructional method well described by E. Aronson, N Blaney, C. Stephan, J Sikes, and M. Snapp in 1978: *The Jigsaw Classroom* (Beverly Hills, CA: Sage). A modified version of this procedure includes an emphasis on two different perspectives. The presentation will include the instructional plan given below:

Steps to Organizing Group Discussions of a Modified Jig-Saw

1. The teacher begins by explaining the first article (a quotation from Donald Kennedy) and describing the following procedures for the lesson:

2. Divide the class into three groups. Each group will read an assigned section, e.g., group one will read section one on "Environmental Risk." Group two reads "Unforeseen Impacts." Allow at least five minutes for the time of silent reading.

3. Divide each of the three reading group into two groups: A. advocates for biotechnology with the belief that more science is good; B. eco-activists who want to preserve the environment and human health with a suspicion that science can cause problems. Assign students to role play these attitudes/perspectives. Each reading group will meet for at least ten minutes to argue their points and arrive at conclusions. Have multiple small groups.

4 Assign at least one advocate of biotechnology and one eco-activist from each reading group to meet with similar representatives of each of the other reading groups. Organize many small new groups with representatives of each reading to explain their conclusions or problems to representatives of the other readings. Allow at least 15 minutes.

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SCIENCE, CREATIONISM AND RELIGION: RESPONSES FROM THE CLERGY

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A long and changing history

For hundreds of years many people have seen religion and science as conflicting world views or doctrines. Discord between Galileo and his church is probably the best known example, made popular again via the best seller *Galileo's Daughter*. In the 20th century, science educators and people supporting evolution have come under fire by fundamentalist Christian denominations. Events in Kansas, Louisiana, and Michigan are recent controversies regarding evolution education that illustrate the recurring conflict of world views.

The evolution/creation public education controversy itself has a long and variable history. Ronald Numbers' (1992) *The Creationists* details the changing nature of creationists' views which precludes simplistic characterizations of the dispute. Singham (2000) splits both science and religion into two subgroups-elite science, popular science, elite religion and popular religion. Elite science is represented by the scientific community while popular science represents mistaken views held by the general public regarding natural phenomena. Elite religion is characterized by the clergy of mainstream religions while popular religion reflects a view of God that is most at odds with biological evolution. The crux of the matter is that these relationships have changed over time and Singham maintains that a questionable contemporary alliance between elite science and elite religion permits both to combine forces against popular science and popular religion.

Since at least the turn of the century the scientific community has overwhelmingly accepted biological evolution , but when creationists' arguments are put before the general public, most citizens are confused. Both evolutionists and creationists appear to cite a great deal of evidence and the arguments seem to point to a genuine scientific debate. Consequently, when creationists ask for equal treatment of evolution and creationism in science classrooms, the general public views the situation as a "perfectly reasonable request for fair play" (Volpe, 1984; Mayer, 1984). According to several polls (Ching, 1984; Edwords, 1981), many Americans prefer that both evolution and creationism be presented to high school science students. A 1991 Gallup poll indicated that 47% of Americans agreed with the statement, "God created man pretty much in his present form at one time within the last 10,000 years."

Unfortunately, we cannot expect the general public to obtain the level of scientific literacy necessary to understand why most creationists' empirical claims are unsupported. Moreover, acceptance of evolutionary theory is largely dependent on an individual's understanding of the nature of science (Clough, 1994; Dagher and BouJaoude; 1997).

Despite an increased emphasis on the social studies of science and its implications for science education, science teachers and their students continue to exhibit misconceptions regarding the nature of science (Johnson & Peeples, 1987; McComas et al., 1998; Ryan & Aikenhead, 1992). John Moore (1983) claims that the evolution/creation controversy is, in large part, a result of misunderstandings concerning the nature of science:

> ...it becomes evermore important to understand what is science and what is not. Somehow we have failed to let our students in on that secret. We find as a consequence, that we have a large and effective group of creationists who seek to scuttle the basic concept of the science of biology.... a huge majority of citizens who, in "fairness," opt for presenting as equals the "science" of creation and the science of evolutionary biology.... It is hard to think of a more terrible indictment of

the way we have taught science.

Johnson & Peeples (1987) determined that acceptance of evolution was significantly related to understanding the nature of science. As students' understanding of the nature of science increased, they were more likely to accept evolutionary theory. Clough (1994) suggested how more accurately conveying the nature of science can diminish students' resistance to evolution education.

Evolution Education

However, students' understanding of the nature of science is but one factor that teachers must consider when teaching biological evolution. Other stakeholders affect science teachers' work and such individuals are often convinced of an irreconcilable conflict between their world view and science. The authors have had students say they're not sure whether they can believe what teachers say in their science classes, because they consider themselves to be Christians-with the implication that fundamental conflict exists between the scientific conclusions (and processes) they're taught in school and the ideas behind their religions. Parents are sometimes even more vocal than children.

"Evolution" is among the key words raising red flags in peoples' minds. Some see evolution as an atheistic, heretical idea. As a college science professor, one of us had a student provide her with creationist materials, as a gift, and another of us had a student who wasn't sure she could accept evolution (although she wasn't really sure what it was) while still being a good Catholic. Of course these are not isolated instances. Major science teaching organizations readily acknowledge the potential for conflict when teaching evolution but stress the importance of evolution in science teaching (AAAS, 1972; NABT, 1995; NSTA, 1997).

Events like these started us thinking. Most Christian denominations in the United States do not view the entire Christian Bible (hereafter referred to as simply the Bible[1]) as the inspired, inerrant word of God, *i.e.*, a book to always be taken literally. In fact, most of these denominations have issued statements acknowledging the overwhelming evidence for biological evolution and other scientific conclusions (National Center For Science Education, 2001). Official representatives from the denominations see little conflict between science and religion.

We suspect that fundamentalist 'attacks' on science probably hurt not only science, but also mainstream U.S. Christian denominations. Students, parents, school board members, and other stakeholders may erroneously believe fundamentalist-based critiques of evolution and science reflect their own denomination's position. If so, this would unnecessarily misrepresent church doctrines and hamper science education.

Hence, the science education community might have a rarely considered ally in mainstream religions found in this country. However, a religious denomination's position on such matters is usually not disseminated to its members in an officially authoritative manner. Rather, such views are filtered through clergy that serve individual churches. What views do local clergy-who directly influence parishioners-hold on the nature of science and religion? What do they tell parishioners struggling with apparent conflicts between the worldviews? An understanding of how local church leaders see the relationship and tension between science and religion could help science teachers better understand the complex nature of the evolution/education/public education controversy.

We have designed this study, then, to determine clergy's views on these issues. How do they see religion and science relating to one another? What do or would they tell their parishioners about science and religion?

We live in a world dominated by the technological applications of scientific ideas and by the naturalistic empirical way of thinking characteristic of science. We also live in a world where many people rightfully place great importance on their faith in a supernatural being and their membership in a church. The U.S. is a highly pluralistic society represented by many different religions and perspectives even within a particular religion or denomination.

The exploratory investigation presented here represents a pilot study to inform further research and provide potentially useful insights for science educators..We examined the views of eight Christian ministers/priests about evolution, creationism, science, and religion. The purpose of the pilot study was not to create generalizable data or conclusions. Rather, we wanted to create a questionnaire/interview protocol that would (a) determine clergy views about evolution, creationism, science, and religion, (letting us compare their views with those generally accepted by the science education community), (b) potentially give us useful information we could give to students or colleagues struggling with these issues, (c) begin the process toward a larger study which *would* create generalizable data or conclusions.

Methodology

The Research Instrument

We created an instrument designed with dual purposes. The first was to ascertain respondents' viewpoints about key issues separating evolutionists and some types of creationists, as well as views about the nature of science and religion. The second purpose was to elicit clergies' comments that might be useful to science teachers and science teacher educators concerned about science and religion (or what to tell their own students about the issue). The initial 28 Likert items also stimulated respondents' thinking on the brief questionnaire that followed. (See Appendix A).In addition to asking respondents what they believed were the major ideas in the theory of evolution, we also asked "How would you counsel a parishioner who felt that accepting the tenets of the scientific theory of evolution meant giving up their belief in God or Christianity?" and "How do you respond when people say the Bible has been proven false by science?"

Instrument items reflected prior literature and included a few modified items from Sinclair & Baldwin's (1997) study of college student views about evolution and religion. Scott's (2001) article discussing a continuum of creationist beliefs was also fruitful in helping us create survey items to discern whether respondents held particular creationist beliefs (e.g., old vs. young earth creationism, intelligent design, etc.). Dagher and BouJaoude's (1997) study of college students religious beliefs and views on evolution was also helpful.

Testing & Refining the Instrument

We interviewed eight ministers for this pilot study. The ministers were generally local. We began with a campus minister and other member of the Campus Ministry Advisory Board (Calif. State Univ. Long Beach). Other interviewees were referred by members of this board or were personal acquaintances of the authors.

As mentioned above, a primary purpose of the pilot study was to test the instrument, refine items and determine recurring themes for inclusion in future interview/survey protocols. The participants were two women and six men of which two were Presbyterians, five were Methodists and one was Catholic. Two of the ministers have doctorates, one in religious education and the other in general ministry and administration. Included in this pilot study was a professor of Religious Studies who teaches a course entitled "Religion and Evolution" and a campus minister. All but the religion professor have attended seminary, i.e., they have degrees beyond a bachelor's. Ages of participants included two in each of the following age categories: 20-29, 40-49, 50-59, and 60-69.

The surveys and interviews were jointly administered by the first two authors. The ministers were interviewed individually and most interviews lasted over an hour, with the shortest being 45 minutes and the longest being 105 minutes.. The subjects were given the 28 Likert items and asked to complete them, after which we went through each item as a three-some to ascertain which items respondents thought were unclear. Afterwards, we asked the three open-ended questions. Both researchers took copious notes, asked for clarification and re-read relevant quotes to be sure that we had accurate notes. The first two interviews provided us with the most information regarding changes to items in the survey. Minor changes in wording of items took place between the first two interviews and the last six. These modifications do not reflect changes in content and intent, but were made to make the questions more understandable and to keep respondents from being distracted by tangential issues, e.g., referring to God as "God" and not "He".

Data Analysis

Interview data and responses to the open ended questions were sorted into groups as various themes emerged. The researchers did this independently and compared both the emergent themes and the sorting of quotes. We discussed differences and reached consensus about themes expressed by respondents. Five major themes emerged.

Survey items were similarly categorized. In this case, we used predetermined categories based on the intent of the questions. Categories included relationships between science and religion and the nature of science and religion. Additionally, the survey also examined the extent to which respondents held a literal interpretation of the Bible, were philosophically materialistic, and theistic. It also assessed various types of creationist-associated beliefs. Survey responses should have allowed us to determine where the respondents fell along the creationist continuum (Scott, 2001).

Data and Analysis

In this study we surveyed and then interviewed eight ministers regarding their thoughts on biological evolution, creationism, science, and their religions. In a society where creationist views sometimes play a role in how and what students learn about evolution, we thought it worthwhile to learn more about how ministers view these issues-since ministers may be a source of information and counseling for students parents, and other public school stakeholders regarding the relationship between religious faith and accepting biological evolution.

Our small sample focused specifically on Christian ministers, but even within that common faith myriad positions exist and the perspectives reported here in no way are claimed as representative of Christian clergy in general. In looking at our data analysis, readers should always keep in mind this work was designed as a pilot study to provide potentially useful insights for science educators and for further research. Within this framework, we nevertheless found patterns amongst the ministers' responses.

Survey Data

The sample size was too small to do meaningful statistical analysis. However, survey responses did yield useful information. The items that were grouped by theme/topic maintained internal consistency. Findings from the survey included:

- None of the respondents were young earth creationists and none took a literal interpretation of the Bible.
- Participants agreed with the statement "I believe there were long time gaps between parts of the Genesis story,"but they were split on the issue of whether creation took seven days (regardless of the length of a "day").
- They all believed evolution occurs in all living organisms and each individual organism was not individually created. However, they had a tendency to believe that some (not all) organisms were separately created and evolution occurred within kinds.
- Their understanding of the nature of science is stronger than we had anticipated. They all understood that scientific theories are tentative, represent our best understanding to date, and are based on data. Because of this, they had difficulty responding to item #19 (evolution is a theory, as such it's highly speculative and not a proven idea). They took issue with "highly speculative".
- The group feels that science and religion do in fact overlap at times. They strongly believe that science and religion can coexist.
- All respondents generally believe in a God who intervenes directly in the physical world and plays a role in evolution.

Interview Data

Science and the Purpose of the Bible

Some creationists view the Bible as an important document for understanding life's creation and the earth's history. Most young earth creationists accept a (more or less) literal interpretation of the account given of the earth's history in Genesis. Some old earth creationists (Scott, 2001) also come close to accepting a literal interpretation of the Genesis explanation, *i.e.*, each 'day' in Genesis was hundreds of thousands of years long, or long time gaps occurred between each day.

Every minister we interviewed believed otherwise. All saw the Bible as important, but not as a source of information for science classes, and not as a document meant to be taken literally. All saw the Bible (and Genesis) as myth, metaphor, or story-religious statements meant to convey important meanings beyond the literal words. (Note: initials in parentheses following quotes are coded to identify individual respondents.):

> "I love the creation story, but I don't see it as factual. God is part of it, and we are caretakers of creation. The story tells us about who God is, and our understanding of God. ...The Bible is stories. There is truth in the stories, but they are not based on fact. ... Facts of a story may be incorrect, but the stories point to something beyond their facts. They are not designed to relate to historical facts. They are stories." (AM)

> "The Bible tells us who God is but tells us nothing about science." (TJ)

> "A literal interpretation distorts what's there, and misses what's there. The stories are at the heart of the community-stories that have been handed down for many, many years. The stories are meant to be religious statements. They don't need [scientific] explanations. ... Narratives and myths don't require defense or proof, but literal interpretations do. ... The Bible is meant to be metaphorical, not literal. If you make it literal, you make it into an idol-and the Bible is about *not* worshiping idols." (AJ)

> "The Bible is storytelling. It's imaginative, so it can't be proven false by science. How can you falsify the creative?" (JQ)

Constructivism & Religion

In *When Children Ask About God* Harold Kushner (1971, p. XXIV) explicitly expresses his indebtedness to the ideas of Piaget in formulating his own perspective regarding how to nurture children's religious development. Although our interviewees never referred to Piaget, constructivism, or conceptual change, they nevertheless made frequent statements paralleling these general ideas. Rather than discuss changing preconceptions about evolution and adaptation, as science educators do, the minsters discussed changing from a concrete or literal interpretation of the Bible toward more abstract understandings. For example:

> AJ, who mentioned people often giving up their beliefs in literal stories of the Bible around age 15 or 16, went on to say, "Changing religious views takes time. It's hard [for people] to give up what they've been taught. ... need to discuss why it's difficult to give up untenable views, why they're hard to give up-for some 'it's what I've been taught, I don't want incur the criticism of my parents or my community.' " (AJ)

> "We need to gauge the Christian learning curve because many folks are literal in their faith."(JQ)

> "Another thing that gets in the way is not being able to see how to hang on to an old idea and accept a new one. ... We need practice in what I call 'used to' thinking, *i.e.*, reminding students of times they used to think one thing and now think another." (GW)

Stumbling Blocks Toward Accepting Evolution

During the course of the interviews, the ministers discussed various stumbling blocks parishioners and others have had that interfered with full acceptance of ideas about evolution.One stumbling block, previously mentioned, is that some people interpret the Bible literally.

> "The issue is not religion, it's where you get your faith from. If you undermine scripture, and scripture underlies everything in your faith, then you've attacked an underlying thing." (TJ)

This issue, though, may involve more than mere intellectual conflict. Students may feel that challenging a literal interpretation of the Bible challenges not only their beliefs, but also challenges their family, community, or church:

> Beliefs that interfere with accepting evolution include the idea that the Bible is to be interpreted literally, and the inerrancy of the church's authority (*i.e.*, questioning the church is not OK). (notes from GW interview)
>
> "K-12 students are interested in the question [about science and religion compatibility]. The real question is usually something different for adults. For example, grandma said something, she's my model, and I don't want to contradict her." (TJ)

Respondents mentioned other stumbling blocks, though. "MV" made the point that, to some, accepting evolution is seen as devaluing humans.

> "The value of the individual is important. With evolution, we run the risk of saying we emerged by pure chance, implying that we have no value. Creationists say that you have been created with intent, therefore you have value." (MV)

This point, he went on to say, is a particularly large stumbling block for early adolescents, who are developmentally self-centered. Believing in evolution makes them appear less important, he said, taking them away from the center of the universe-where, as early adolescents, they feel they belong.

Finally, one respondent also pointed specifically to lay people teaching Sunday school as a source of misinformation (including misinformation about understanding the Bible's Genesis story):

> Sunday school teachers contribute to the problem. The curriculum is usually okay but the less informed beliefs (of the Sunday school teacher) come into play-in essence they are uncredentialed teachers. They may be theologically unsophisticated or immature. Youth workers also propagate a literal/fundamentalist approach through "praise music". (notes from JA interview)

Suggestions for Talking with Parishioners

Like constructivist teachers, the ministers felt that counseling of parishioners who struggle with a conflict between evolution and creation has to start with an understanding of what the person believes and understands. They would start by asking questions and listening.

> "In counseling a parishioner who felt that belief in evolution negates his/her faith I would start at points of commonality. We both believe in creation. We'd compare their concept of a day and mine, the steps that took place, etc. We'd compare where we agree and disagree but start with the common ground. In order to heal the breach it helps to start with common ground otherwise the chasm gets larger." (WH)

> "I would question the student. Can you not believe in God if you don't believe in a 6 day creation? Let the students talk first, find out their thinking and then ask questions. Why is it that these two ideas (God the creator and evolution) are incompatible? Is it impossible to have a Creator billions of years ago versus a 6 day creation? Students need to make some interpretations themselves -- how long is a "day"? what about dinosaurs? The early peoples who wrote the Bible didn't have tools to age date." (GW)

The next step for GW and WH is to point out contradictions in the Bible, not just in the evolution story. This is not meant to undermine faith, but meant to get the person to look at the Bible differently. As mentioned earlier, these ministers do not agree with a literal interpretation of the Bible.

> "Who wrote the Bible - not Adam and Eve, they couldn't write. Writing wasn't started until long after creation." (GW)

> "I don't believe in seven 24-hour days. Who was there taking notes? There are two creation stories which conflict with each other. Genesis 1 has a seven day creation and Genesis 2 has a one day creation. The order of events differs in the two stories. In Genesis 1 man is created at the end, in Genesis 2 man is created in the middle. The order of creation is problematic, too. Plants and animals were created before the sun. How could photosynthesis occur?" (WH)

Just as the game of *telephone* results in changed messages, ministers said, changing the way in which a story is recorded yields different messages. The Bible started as an oral tradition and was only later put down on paper. The story would necessarily change as retold over time. In some cases we can go back to source materials and see differences in the current Bible.

> "I would question students what they mean by literal interpretation. People were moved to write about their experiences and history - not God. They were moved by God, but were not taking dictation from God. Suggest an analogy - you have some experience and you want to record it - first you draw a picture, you write about it based on the picture and your remembrance. What you have written is not reality but a remembrance of reality - the same is true with the Bible. Bible is not literally God's words but the world of humans." (GW)
>
> Firstly, science is not out to prove the veracity of the Bible. Second, the Bible represents oral traditions, not a literal, factual book. The United Methodists say that "truth is contained in scriptures" as opposed to the scriptures being literally true. The Bible gives us background, stories to inform our faith, and has sayings attributed to Jesus as teacher and leader. It happened so long ago there is no way to know if the account is true. It is history and oral tradition, not a literal document therefore not something that can be deemed true or false. (JA)
>
> "The Bible is a guideline, not inerrant in terms of scripture. There are too many opportunities to look at scrolls to see that scribes made errors. They left out paragraphs, repeated the same line in different places, etc. The Bible is a faithful attempt of people to put down God's interaction with people over time." (WH)

The ministers also felt comfortable in sharing their own beliefs with parishioners. We know from research into students' willingness to give up naïve scientific understandings that conceptual change is dependent upon a new, more attractive model being present. The ministers, by sharing their understanding and views, are providing an alternative way of understanding the Bible or creation.

> "I do not see a problem in terms of compatibility between creation and evolution. I am more theistic. I believe creation/evolution is a process and God could be involved in the process." (WH)

> "You're combining what cannot be combined. Evolution is not a denial of faith, but it can be an affirmation of faith." [If you see evolution as evidence of how the world came to be, and it's one of the ways the mystery of life is disclosed, how God's hand is revealed.] Biblical narratives are not meant to be scientific statements; they are (stories) that express universal truths. Creation is what God has caused." (AJ)
>
> "To me, the message of the Bible is simple - The world is good and it is God's. Our job is to take care of it." (GW)
>
> "The Bible sequence may not be accurate but the role of God is." (JM)
>
> We don't know how long a [Biblical] year was at the time. The creation story says creation took, six days, but each "day" might have been much longer than a 24 hour day. ... The story does seem to follow evolution. How could the storytellers have known that?" (JA)

The ministers would try to help their parishioners see the role and purpose of the Bible as a guideline for living as opposed to a recording from God. It contains story, myth, and narrative and requires no defense. They repeatedly pointed out how it is not something that can be proven true or false in a scientific way. Science has helped us understand the Bible and points to some historical events that align with biblical stories, ministers said, but that does not make the Bible an authoritarian historical or scientific text.

Conclusions

Relationships between Science & Religion

When examining relationships between science and religious ways of understanding, scholars tend to use basically similar typologies (*e.g.*, see Barbour 2000, Nord 1999, Ratzsch 2000). For example, Barbour (2000) categorizes the relationship between science and religion as being one of either conflict, independence, dialogue, or integration. Similarly, Ratzsch describes science and religious beliefs as being independent, inseparably blended, or related in various ways. Each of these categories has sub-categories.

Nord's (1999) categories relating science and religion are similar to the two just mentioned. His four categories are slightly simpler and more general than the others, serving better our purposes in this paper. He describes the relationship possibilities as:

1. *Religion trumps science.* "When science and religion conflict, only religion provides reliable knowledge. It is through inerrant scripture or religious tradition that we come to know the ultimate truth about nature. (p. 29)" Biblical literalists and most creation 'scientists' most clearly fall into this category.

None of the clergy we interviewed fell into this category and, indeed, most seemed vehemently opposed to a literal interpretation of the Bible.

2. *Science trumps religion.* "When science and religion conflict, only science provides reliable knowledge. It is through the methods of science that we learn the ultimate truth about nature. (p. 29)" Positions associated with this category would probably include those called scientism, philosophical naturalism, and perhaps atheism.

None of the clergy we interviewed fell into this category, either.

Although *merely opinion*, it does seem as if much of the apparent conflict between science and religion comes from people either espousing one of the above two viewpoints, or having a conception of science or religion based on one of the viewpoints. One of the minsters, GW, echoed this opinion. He said that decisions like the one made by the Kansas Board of Education about teaching evolution/creationism were 'bad news' for many Christians because they hold evolution to be compatible with their religious views. Decisions like the Kansas one "throw stones," as he said, at the ideas they believe in. For them, the ruling implies (incorreclty) that science is bad or wrong.

3. *Independence*. "... science and religion can't conflict because they are incommensurable: each has its own methods; each has its own domain. . . . One common expression of this view is that science asks objective "how" questions, while religion asks personal "why" questions. (p. 29)"

The majority of the clergy we interviewed expressed views indicating they believed either the ideas within this category, or a combination of this category and the next. Here are some representative quotes:

> "The Bible is not concerned with how things happen. 99% of it is about why things happen." (TJ)

> "Can a mathematician invalidate a symphony? ... The Bible is about revelation and who we are with God. Everything it does is just a tool toward that goal. In that sense, the Bible and science are incompatible because they're about different things. ... They may share the same stadium, but they have different rules." (TJ)

> "The Bible is storytelling. It's imaginative, so it can't be proven false by science." (JQ)

> "Science is not out to prove the Bible false." (JA)

> "Biblical narratives are not meant to be scientific statements; they are (stories) that express universal truths. Creation is what God has caused." (AJ)

> "Ideally, evolution should be taught in science classrooms. In literature or world history, teach stories of creation from around the world. There are myriad stories. My guess is that this [evol vs creationism] is not an issue in India, where they're got multiple creation stories. They are not fighting over which is best. " (MV)

Interestingly, only one minister agreed with the survey statement "Science is based on data; religion is based on faith." In some ways this data may appear to conflict with the above statements. We believe, anecdotally, this is because the ministers' would say they conceive of religion as being based on more than faith. One minister overtly expressed this viewpoint, talking about the role of culture in our understanding of the Bible, the Bible as metaphor, and science as a way to clarify faith. That doesn't detract, however, from their ideas about science and religion as being separate and not competitive ways of knowing.

4. *Integration*. " . . . science and religion can conflict and can reinforce each other, for they make claims about the same world. . . . a fully adequate picture of reality must draw on-and integrate-both. (p. 30)" Although the independent viewpoint may still be more widely accepted than that of integration, the last few decades have seen a shift toward acceptance of this latter view. Ian Barbour and Arthur Peacocke are among key scholars in the science/religion debate who espouse this view.

Some of the ministers we interviewed made statements indicating acceptance of an integrated view of science and religion. For example:

> "Evolution is a process of how God keeps the universe going." (TJ)
>
> "Science is moving toward unity and one-ness, and I see that as evidence of the divine." (AJ)
>
> "Why are [science and religion] considered incompatible? Can't there be a creator, with creation starting billions of years ago?" (GW)

One minister in particular, "WH," was particularly strong in his beliefs on this issue:

> "I believe creation/evolution is a process and God could be involved in the process. . . . God was involved in creation. We peel away the leaves on a head of lettuce to reveal what's underneath. That does not negate God's involvement." (WH)
>
> "The Bible and science go hand in hand. History, culture and informed criticism of the text help us make sense of scripture. The Church has often changed its mind or position on things through time (*i.e.*, the role of women, views on slavery, the role of homosexuals). In many cases it is science that has shed light on the issue." (WH)

> “Science and theology can go hand in hand to understand creation. There is always a leap of faith somewhere. I believe God can act in ways seen and unseen.” (WH)

Implications for teaching

When the ministers learned more about why we were conducting the study many offered ideas about how the evolution/creation debate might be addressed in classrooms.

1 Invite a panel of clergy and let students ask questions. Students can invite their own pastors to participate. Clergy can hold on to the ambiguity, maintain their faith and still accept science is like a "breath of fresh air" to students. "It's what they are looking for." (GW)

2 Ask students questions and provide alternatives that keep elements of their original ideas while offering something different (promote an "I used to think" environment). Examine the evolution in your own thinking so students can see that you have changed your beliefs over time (in essence, modeling the "I used to think" approach). (GW)

3 Help kids enjoy intellectual puzzles and figuring things out. This will help them examine their own thinking and beliefs. Most kids get stuck in regards to their faith and they are not encouraged to question or examine their thinking. (GW, TJ, MV)

4 "I am not an advocate for teaching creation in the schools. The creation story is primarily faith and theology and I don't want persons of no faith teaching doctrine." (TJ)

The campus minister provided us with a copy of a newsletter addressing the issue of science and religion. The newsletter provided suggestions for campus ministers to begin a dialogue between the faith and science communities (Koch, 2001). The author suggests celebrating the work of scientists on your campus, starting book groups or a movie discussion group centered around works portraying the intersection of science and religion, subscribing to faith and science publications, keeping informed about issues relating faith and science, and beginning brown bag discussion groups for faculty and students to discuss these issues.

Teachers may find implementing some of these ideas difficult in particular contexts. An alternative might be to devote a bulletin board to portions of the book *Voices For Evolution* (McCollister; 1989) containing position statements in support of evolution from scientific, religious, and education organizations.

The mutual respect advocated by the clergy interviewed in this study. appears to us to be a critical beginning point in diminishing students resistance to evolution education, and it echoes earlier advice by Clough (1994) and Dagher and BouJaoude (1997). However, students must also come to understand that science has adopted epistemological and ontological presuppositions which differ from traditional belief systems. For instance, while the ministers interviewed here often spoke of God's hand in evolution, that view-while reflecting some scientists' personal beliefs-is not open to scientific investigation and hence not part of the scientific world view. This does not mean that the scientific community is atheistic, only that science can take no position on the supernatural.

Similarly, clergy may be in a better position than science educators to discern the epistemological and ontological presuppositions underlying religious ways of understanding the world. As articluated by most of our interviewees, science and religion often look at the same world through different filters. Clergy, being fluent in the language of religion, have the knowledge and credentials to be critical of statements or ideas claimed to be religiously founded. Religious leaders may be among those best suited for speaking critically about issues that come from seeing religious traditions through a scientific worldview.

The initial mutual respect advocated by this study's interviewees creates an opportunity to address the nature of scientific thinking and the importance of understanding what is gained (and lost!) in "border crossing" to that perspective. In this way, students' personal religious beliefs are respected while developing a deeper understanding of both science and religion's place in human understanding. Students' education, science and religion would all surely profit from a deeper understanding of the rarely articulated epistemological and ontological presuppositions of science.

Next Steps

With the pilot study completed, we will likely now select a target group of clergy to study, *i.e.*, a more representative sample of clergy than examined in this study. We are considering a variety of possible groups. For now, the most likely group for study seems to be campus clergy. Within the realm of college biology teaching, campus clergy represents a group accessible-and potentially useful-to faculty and students. Thus, examining the views of campus chaplains regarding evolution, creationism, science, and religion has the potential to be useful for college biology (and geology) faculty, science educators, and students.

With initial testing indicating we have created an instrument with face validity, we can now more formally test it for reliability and validity. A conference is held each summer for campus ministers. Our tentative plan is to distribute the reliable and valid instrument at this conference. This will permit us to have a larger and more representative sample of clergy. Although the survey was relatively unhelpful in the current study, our expectation is that we would acquire more varied and useful data when it is distributed to a sample including a wider range of views.

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Appendix A. Pilot Survey & Questionnaire

Demographic Information

Age: 20-39 40-49 50-59 60-69 70-140 >140 ☺

If you attended seminary, when did you graduate? __________

Faith: ________________________ Denomination: ________________________

Science background beyond general college requirements? ________________________

____

____

Would you say you are probably more interested in science than the general public? _____

On a scale from 0 (strong disagreement) to 10 (strong agreement), mark the extent to which you agree/disagree with the following statements.

1 _____ I think there is little or no conflict between the scientific theory of evolution and Christianity.

2 _____ Evolution is in some way part of God's overall plan.

3 _____ Based on my interpretation of the Bible, I believe the Earth is flat.

4 _____ Science is based on data; religion is based on faith.

5 _____ God used evolution during creation and we are slowly finding out how God did it.

6 _____ Based on my interpretation of the Bible, I believe the Earth is the center of the universe and the sun rotates around the Earth.

7 _____ The laws of nature are all there is; the supernatural does not exist.

8 _____ I feel that a person believing in the story of Adam and Eve found in the Bible cannot also believe in evolution.

9 _____ The Earth is probably 6,000 to 10,000 years old.

10 _____ I believe in a literal interpretation of Genesis.

11 _____ I believe creation took seven days, but each "day" might have been thousands or even millions of years long.

12 _____ The first cell had to come from somewhere. God has to fit in someplace.

13 _____ I'm OK with animals evolving but not with humans coming from another animal.

14 _____ Evolution doesn't provide any place for religious beliefs.

15 _____ Humans and all other species were specially and separately created.

16 _____ Science deals only in facts, and never with the supernatural.

17 _____ A supernatural being has acted often to cause observed changes.

18 _____ I believe there were long time gaps between parts of the Genesis story.

19 _____ Evolution is a theory, as such it's highly speculative & not a proven idea.

20 _____ God creates separate kinds of plants, animals, etc., and then evolution within kinds occurs.

21 _____ Evolutionary theory conflicts with the Bible and forces people to choose sides.

22 _____ The finding of order, purpose, and design in the world is proof of an omniscient designer.

23 _____ Acceptance of evolution and belief God in can coexist.

24 _____ Life is too complex to have occurred without the presence of an intelligent designer (God) guiding the process.

25 _____ Evolution is one way in which God creates.

26 _____ Evolution applies to other living things, but not to humans.

27 _____ Science is neutral toward religion.

28 _____ Successful scientists can also be devoted Christians.

Use as much space as you like to write responses to each of the following questions:

1. In your view, what are the major ideas in the theory of evolution?
2. How would you counsel a parishioner who felt that accepting the tenets of the scientific theory of evolution meant giving up their belief in God or Christianity?
3. How do you respond when people say the Bible has been proven false by science?

A CARD SORTING TASK TO ELICIT SCIENCE TEACHING ORIENTATIONS

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An orientation to teaching science, defined as "teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" (Magnusson, Krajcik & Borko, 1999, p. 97), has been proposed as a critical component of the pedagogical content knowledge (PCK) model for science teaching. We have designed an activity to elicit prospective teachers' purposes and goals for teaching science. The information elicited during this activity may be useful in articulating a personal philosophy of science teaching.

Protocol for the Card Sorting Activity

When using the card sort as a classroom activity, we suggest that students work in pairs, with each pair receiving one set of scenario cards.

Step 1

One student acts as the interviewer while the second student sorts the cards. The interviewer asks the student to read the set of scenario cards and sort the cards into the following stacks: 1) this scenario represents how I would teach, 2) this scenario does not represent how I would teach, and 3) unsure. While the student is sorting the cards, the interviewer should note which scenarios evoke strong positive/ negative reactions from the student. (To save time, the instructor may wish to read the directions in Step 1 to the entire class. If each student receives a set of cards, they could sort their own cards before pairing for the rest of the activity.)

Step 2

After the completion of this first round of sorting, the interviewer selects a scenario that evoked a strong positive reaction from the student and asks the student to talk about that scenario. The interviewer probes by asking, "How does this scenario support your purposes and goals for teaching science?" Repeat with several more scenarios that evoked strong positive reactions. The interviewer should record the student's purposes and goals for teaching science as they emerge from the conversation. Next, the interviewer selects a scenario that evoked a strong negative reaction and asks the student to explain why her or she rejected the card. The interviewer may need to probe by asking, "What aspects of the scenario would need to be changed before you could place the card in the first stack?" Again, the interviewer should record the student's purposes and goals as they emerge from the conversation.

Step 3

After the initial sorting of the cards and the follow-up discussion, the focus shifts to the cards in the first stack, those scenarios that represent how the student would teach science in their own classroom. The interviewer asks the student to re-examine the cards in the first stack and place the cards in a continuum. The student is asked to place the cards that best represent how they would teach science to the far left of the continuum. After completing the continuum sort, the interview asks the student to describe their decision-making process in sorting the cards. The interviewer probes by asking, "How does this scenario represent your purposes and goals for teaching science?" After identifying smaller subsets of scenarios, asks the student, "How are these cards alike?" By asking the student to explain his/her rationale in sorting the cards on a continuum, the interviewer is seeking to elicit the student's central purposes and goals for teaching science.

Step 4

The interviewer shares her perceptions of the student's purposes and goals for teaching science. The interviewee takes a few minutes to record her insights about her own science teaching identity before moving to Step 5.

Step 5

Within the pair of students, roles are switched and Steps 1–4 are repeated.

Table 1

Elementary Science Card Sort

Number	Elementary Science Teaching Scenarios
1	You, as a teacher, are teaching a unit on space. Each day during the unit you read to the class from a chapter book about the solar system. After reading about a particular planet, you ask students to make a statement about the planet. You record these statements on the board for inclusions in a letter sent home to parents at the end of the day.
2	You, as a teacher, want to teach about insects. You decide the best way to do this is to have children cut out pattern body parts and assemble these into an insect that is put on the bulletin board.
3	In a unit on cells, you, as a teacher, decide that the best way to learn about parts of a cell is for students to assemble a "jello cell," where various shaped candies represent different cell parts.
4	You, as a teacher, begin a new unit by asking students what they already know about the topic. You use a KWL chart to record the students' prior knowledge.
5	You, as a teacher, have students observe earthworms and generate questions about earthworm behavior. Each small group designs and carries out their own experiment to test a hypothesis related to the group's questions.

Table 1 (continued)

6	You, as a teacher, require your students to participate in the school's Science Fair. You remind students and parents that the act of doing science is more important than the results.
7	Your students are intrigued with a toy water rocket that a classmate has brought to school. As a group, the students identify questions and ways to explore how the rocket works. You help the students organize into investigation teams. You investigate along with the students.
8	You, as teacher, teach a recycling unit by presenting important information about recycling to your students.
9	You, as teacher, encourage students to explore their own interests about the natural world. One of your students looks up information about whales while another student sets up an investigation to study bread molds.
10	You, as a teacher, set up learning centers for a unit on Newton's Laws of Motion. Using resource books from your school's library, you select a variety of fun, easy-to-do activities.
11	You, as a teacher, want your students to learn about simple machines. You decide the best way to do this is to provide the students with broken household gadgets and appliances to take apart.
12	You, as a teacher, set up a "Sink or Float" learning center in one corner of the room. On a weekly basis, you change the materials available at this center.
13	You, as a teacher, want students to learn the phases of the moon. You decide to ask your students to observe and make sketches of the moon each night for a period of one month.
14	You, as a teacher, want your students to learn about classification. You have students sort a collection of leaves into different categories based on the leaves' properties.

Table 1 (continued)

15	You, as a teacher, give students batteries, bulbs and wires. You encourage the students to find all the possible ways to light the bulb.
16	You, as a teacher, design a science unit around the question, "What's in our drinking water?"
17	You, as a teacher, place bird feeders outside your classroom window. You ask students to carefully and accurately record their observations of bird activity in an electronic journal.
18	Your students have just completed a bridge-building project. For the next unit on simple machines, you ask the students to make their bridge moveable using a combination of two or more simple machines.

Table 2

Secondary Science Card Sort

Number	Secondary Science Teaching Scenarios
1	You, as a teacher, design a unit on drinking water by organizing lecture/discussion materials, and designing laboratory activities.
2	You, as a teacher, have your students first engage in laboratory activities, then follow-up with class discussion.
3	You have each student select a topic from a list that you provide. Working individually, the students may use the school library and/or the Internet as resources for writing a report on their selected topic.
4	As a means of assessment, you have students role-play the process of meiosis.

Table 2 (continued)

5	To help your students understand arthropod characteristics, you organize a series of stations. Each station contains representatives from a different class of arthropods.
6	You, as a teacher, decide the best way for students to learn about volcanoes is to have them build models of volcanoes.
7	In a weather unit, you have students take daily temperature and rainfall readings, as well as estimate wind speeds.
8	As a teacher, you organize a unit on drinking water by having students design their own investigations related to drinking water.
9	You, as teacher, begin a new unit by presenting basic background information and terminology before moving into the laboratory activities.
10	You, as a teacher, begin a pendulum unit by giving students strings and weights. By letting the students explore on their own, they will be able to discover which variable (length of string or mass) affects the number of swings per minute.
11	You, as a teacher, decide the best way for your students to learn about organic compounds is to organize the students into small groups. Each small group will present information on a different type of organic compound.
12	As a means of assessment, you give the students a multiple-choice exam.
13	As a teacher, you begin a unit on light by asking students to explain how they can see the writing on the chalkboard.
14	As a teacher, you decide the best way to teach photosynthesis is to design a well-organized series of lectures.

Table 2 (continued)

15	In a unit on evolution, you have students debate creation vs. evolution.
16	When designing laboratory activities, you include clear, easy to follow, step-by-step directions for the procedure.
17	As a chemistry teacher, you have the students memorize the first 20 elements of the periodic table.
18	In planning a unit, you collect a variety of activities for the students to do. You organize the unit by doing a different activity each day.
19	As a teacher, you have your students observe earthworms and generate questions about earthworm behavior. Each small group designs and carries out their own experiment to test a hypothesis related to the group's questions.
20	As a teacher, you begin a unit on plate tectonics by having your students read the chapter in the book.

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USING PROBLEM-BASED LEARNING IN A SCIENCE METHODS COURSE

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Knowledge is the product of human beings in the state of continual negotiation or conversation. Education is not a process of assimilating the 'truth' but a process of learning to 'take in hand what is going on' by joining the 'conversation of humankind.' Collaborative learning is an arena in which students can negotiate their way into the conversation."
Bruffee, 1993.

Background

Teaching methodologies, such as PBL, have arisen in response to educational research that has found evidence that even though lecturing may be the most prevalent teaching tool it is arguably the least effective way to facilitate student learning. Meyers and Jones (1983) reported that (a) "While teachers are lecturing, students are not attending to what is being said 40% of the time, (b) In the first 10 minutes of lecture, students retain 70% of the information; in the last ten minutes, 20%, (c) Students lose their initial interest, and attention levels continue to drop, as a lecture proceeds, and most alarming of all, and (d) four months after taking an introductory psychology course, students knew only 8% more than a control group who had never taken the course" (p.14).

Knowles (1989) tracked the origin of the "modern day" school system back to the seventh and twelfth centuries. During that time, schools were established in cathedrals and monasteries in Europe primarily for the preparation of young boys for the priesthood. As a result of the teachers in these schools having as their principal mission the indoctrination of young boys in the beliefs, faith, and rituals of the Catholic Church, they evolved a set of assumptions about learning and strategies for teaching that came to be subsumed under the label "pedagogy."

literally meaning the "art and science of teaching children." When public schools started organizing several centuries later, this model was the one that was used over the Socratic method or Dewey's (1963) constructivism. As a result, elementary, secondary, and higher education became frozen in that model.

It is no wonder that Schrank (1997) believes that the educational model, used by most schools, does not work because it is based on the belief that people learn through listening. As a result, school is not really about learning; it is about short-term memorization of meaningless information that never comes up later in life. In short, the school model was never intended to help people acquire practical skills; it was intended to satisfy interested observers that the knowledge is being acquired -- albeit for a short period of time.

Theoretical background

The historical underpinnings of problem-based learning (PBL) date back to the work of John Dewey (1963) at the University of Chicago Lab School and his commentary on experimental education. The writings of G. Polya (1988), while not specifically aligned with problem-based learning emphasize the need for metacognitive reflection on learned heuristics as a problem-solving tool. In Polya's model, students might review their steps to solving the problem, with an emphasis on extracting generalizable labels such as "visualizing" or "part-to-whole thinking."

Recognizing that Dewey's work could be used in medical school, Harold Barrows, a physician and medical educator at McMaster University in Hamilton, Ontario, Canada, wanted to develop methods of instructing physicians that fostered their own capabilities for reflection of school in ordinary life. While most medical schools, at that time, focused on providing knowledge, Barrows (1985) thought that this was just the first of three interdependent elements:

> (1) an essential body of knowledge, (2) the ability to use…knowledge effectively in the evaluation and care of patient's health problems, and (3) the ability to extend or improve that knowledge and to provide appropriate care for future problems which they might face. (p. 3)

Writings on higher-order thinking also allude to problem-based learning. Grounded in the 1980s, when thinking skills began to be emphasized, this model of problem solving teaches students to think inductively and deductively (deBono, 1976; Feuerstein, Hoffman, Miller, & Rand, 1980; Lipman, Oscanyan, Sharp, 1980; Resnick, 1987). It teaches students to think in the concrete and the abstract, moving through the stages of problem solving from novice to expert. Teachers use this model to develop rigorous thinking experiences for their students. While existing literature on higher-order thinking does not specifically refer to these experiences as problem-based learning, they certainly provide the cognitive basis for contemporary work in the area.

Writings on gifted education also represent early efforts in the area of problem-based learning. The roots of problem-based learning can be found in Parnes, Noller, and Biondi's work (1977) with the Creative Problem Solving Model, Torrence's work (1963) with the Future Problem Solving Bowl, and programs such as Olympics of the Mind and Renzulli and Smith's work (1979) with gifted education.

Brain research findings published by Caine and Caine (1991) mention that holistic models of curriculum are brain compatible. In addition, the research supporting the constructivist theory of learning (Brooks and Brooks, 1993), which argues that the learner constructs meaning in the mind by connecting prior knowledge to new learning, points toward problem-based learning as a viable curricular frame.

Barrows and Tamblyn (1980) defined this new method, problem-based learning, as "the learning that results from the process of working toward the understanding or resolution of a problem" (p. 18). They summarized the process as follows:

- The problem is encountered first in the learning sequence, before any preparation or study has occurred.
- The problem situation is presented to the student in the same way it would be present in reality.
- The student works with the problem in a manner that permits his ability to reason and apply knowledge to be challenged and evaluated, appropriate to his level of learning.
- Needed areas of learning are identified in the process of work with the problem and used as a guide to individualized study.
- The skills and the knowledge acquired by this study are applied back to the problem, to evaluate the effectiveness of learning and to reinforce learning.
- The learning that has occurred in work with the problem and in individualized study is summarized and integrated into the student's existing knowledge and skills (pp. 191-192).

More recent works (Delisle, 1997; Dixon-Krauss, 1996; Fogarty, 1997; Hedegaard, 1990; Lumsdaine & Lumsdaine, 1995; Vygotsky, 1986) have related the importance for students of all ages to work in groups, interact with one another, and work on purposeful learning, including PBL, while they construct knowledge together.

The relevance of this work to science teacher education

In the typical science methods course for preservice elementary teachers the issues of assessment, inquiry-based science, selection and adoption of science materials, cooperative learning, how children think, and questioning strategies, among others are addressed. Teachers of methods courses would like their students to confront some of these issues creatively and come up with viable answers to problems that are faced when teaching science in the elementary school. Problem-based learning is one of the instructional techniques that I have used to address these issues with my methods students.

The National Science Education Standards (NSES) (National Research Council, 1996) discusses the science courses that undergraduates take in preparation to be teachers. The NSES (1996) states, "Undergraduate science courses are a major factor in defining what science content is learned. These courses also provide models for how science should be taught" (p. 60). The NSES also posits "learning science through inquiry should also provide opportunities for teachers to use scientific literature, media, and technology to broaden their knowledge beyond the scope of immediate inquiries. Courses in science should allow teachers to develop understanding of logical reasoning" (p. 61). Problem-based learning allows students to use all of these resources while learning about how to teach science.

Instructing methods students about cooperative learning and how students should be placed in groups is difficult unless you model it for students during the methods course. Students in my course are placed in permanent groups that confront problems, conduct research about the problem, and pose alternative solutions both individually and in groups. Accountability is built in through peer evaluation, rubrics, and individual parts of the assignments. It is important for methods instructors to give preservice teachers tools and strategies for use in the classroom. PBL is a tool that teaches cooperative learning, grouping of students, and an inquiry-based methodology for science instruction.

Why change to PBL?

The author teaches courses where students are expected to develop their own perspective on key issues. Students should be learning knowledge in such a manner that they can make practical use of it. Science education should be no different. Clyde Herreid (2001) relates a conversation that he had recently with a colleague:

> "Are you saying that the undergraduate experience was disabling—debilitating?"
> "Yes, undergraduate teaching isn't just neutral—it's hurtful?" (p. 87-88)

This sums up my experience in a nutshell. This is what I felt I was doing to my students. My own reading in sociocognitive frameworks supports this feeling and may have led me to try PBL in my own classes.

Some researchers (Brown, Collins, and Duguid, 1989; Collins, Brown, and Newman, 1989; Rogoff, 1990) look at this type of learning as a type of cognitive apprenticeship, situated in a body of knowledge.

Brown, Collins, and Duguid (1989) emphasize the idea of cognitive apprenticeship:

> Cognitive apprenticeship supports learning in a domain by enabling students to acquire, develop, and use cognitive tools in authentic domain activity. Learning, both outside and inside school, advances through collaborative social interaction and the social construction of knowledge. (p. 39)

Collins, Brown, and Newman (1989) say that effective teachers involve students in learning as apprentices: they work alongside students and set up situations that will cause students to begin to work on problems even before fully understanding them. A key aspect of an apprenticeship approach to teaching involves breaking the problem into parts so that students are challenged to master as much of a task as they are ready to handle. In addition, teachers are encouraged to provide students with varying kinds of practice situations before moving on to more challenging tasks, allowing an understanding that surpasses the use of formulas.

Brown, Collins, and Duguid (1989) relate that cognitive apprenticeship supports learning in a subject domain by enabling students to acquire, develop, and use cognitive tools in authentic domain activity.

The term apprenticeship helps to emphasize the centrality of activity in learning and knowledge and highlights the inherently context-dependent, situated, and enculturating nature of learning. Apprenticeship also suggests the paradigm of situated modeling, coaching, and fading, whereby teachers or coaches promote learning, first by making explicit their knowledge or by modeling their strategies for students in authentic activity.

Rogoff (1990) relates that the notion of apprenticeship as a model for children's cognitive development is appealing

> Because it focuses our attention on the active role of children in organizing development, the active support and use of other people in social interaction and arrangement of tasks and activities, and the socioculturally ordered nature of institutional contexts, technologies, and the goals of cognitive activities. Although young children clearly differ from older novices in the extent to which they can control their attention and communication in their general knowledge, there is a useful parallel between the roles of young children and the roles of novices in general in apprenticeship. (p. 39)

The courses taught by the author prepare teachers, geologists, agronomists, and natural resource professionals. These courses are:

- Science methods for elementary education majors
- Exploring Teaching as a Career—the first education course for education majors.
- Environmental Geology/Soil-Air-Water Contamination

Something that all of these courses have in common are a variety of interesting, engaging issues to examine. Still, I found myself frustrated for several reasons:

- Students would not have command of the course material and could not apply the content.
- Students were not reading the background material for class sessions.
- The discussions in my class were teacher-centered. The discussion flowed through me. I knew the answers, had practical experience as a teacher and expected that the students would come around to my way of looking at issues. (For student excitement level using this method of instruction see Ben Stein's performance in *Ferris Bueller's Day Off.)*

The Transition to a More Effective Model of Instruction

My frustration stems from my desire to be an effective teacher at the university level and to teach preservice teachers and other preservice professionals. This frustration has motivated me to adjust my own attitude and seek other ways to instruct my students. Specifically I had to identify:

- Exactly what was not going well with my teaching and what was causing my frustration. These are the items mentioned in the previous section.
- Where I could get some help and support.
- What changes I wanted to make to my courses.

That help came from the Problem-Based Learning Group at Purdue University and being mentored by experienced PBL faculty in education and other disciplines. The first thing that I decided to do was to make an attempt at writing my own PBL scenarios. The next decision was to introduce PBL into the introductory education course.

The introductory course was taught in during the first summer module of 2001 just before attending the Case Study Teaching in Science workshop in June 2001. This course was six weeks in length including a week of field experience at an ethnically diverse school in Indianapolis. Since these students were aspiring to be teachers I thought that collaborative activities would model how they could manage small groups in the classroom. I had an experienced PBL faculty member come in to do some team building with the students, which included an opening activity (see the overhead that I used in the appendix of this paper). That faculty member also explained how he did team charters and used groups in his class. This seemed a good way to transfer some pedagogical knowledge to these beginning preservice teachers.

There are many key issues that are examined in this course but I decided to develop PBL problems out of three key issues: diversity, parent-teacher communications, and looking for a job. Rather then being as wide open as a normal PBL problem, my scenarios were more like guided discovery. I wanted students to use many resources to propose solution to the scenarios that were available like the Internet, the phone, or interviewing teachers. A librarian who belonged to the PBL group conducted a class session on how to do purposeful searches on the web and other library resources.

Students' reactions to these scenarios and the use of PBL during this course were mixed. Students thought that the PBL faculty member that was teaching the class was really the instructor rather than me. They wanted me to lead discussions and tell them what my perspective on the key issues was. Students also wanted me to tell them what they should know from the course reading. This led me to the conclusion that these students were uncomfortable with the new model of instruction. They were used to courses that made them memorize facts and did not challenge them to apply the knowledge to a science education context.

Elements of PBL Used in the Science Methods Course

Team Building

The concept of team building is essential to the success of using PBL in an undergraduate course. Students may not know one another and need you to provide that opportunity. The second day of the course I ask students how they want to be grouped. The answers range from a type of food to picking their own groups. Both methods have been equally effective for me.

Once teams of three to four students have been established I have them do the tower building activity that appears in the appendix of this paper. I provide each team with an equal amount of straws, tape, coffee lids, and index cards. Additional items may also be placed in the bag. The teams then have twenty minutes to complete the task. I am available to answer questions but do not tell them how to do anything. While the teams are working it is interesting to see members of the group assume different roles of director, doer, materials manager, etc. I have not assigned these roles, they have taken them on naturally.

The most important part of the activity comes when the activity is debriefed in a whole class discussion. This is essential especially for a group of preservice teachers. In order to debrief I asked them how the activity went and how they went about building the tower. I then relate the experience to Bloom's Taxonomy. It is remarkable how many of the students come up with higher order and critical thinking elements of building the tower.

Team building continues with each group constructing a team charter and the team profile. The team profile is done after each member of the team has taken two online personality tests and determined:

1. Whether they are a Type A or B personality (http://www.queendom.com/typea.html)

2. What type of role in a group they most gravitate toward: Thinker, Socializer, Director, or Relator (http://www.mentoru.com/pro/ac/asmt.asp?asmt=1)

The team profile can alert you to potential problems like having too many Directors who develop a conflict for the group.

Team Teaching

Librarians have been an exceptional resource when I want to share strategies for conducting research. Alexius Macklin, Information Librarian in the Purdue University Undergraduate Library uses PBL scenarios to have my students locate different types of information on professional organizations, assessment strategies, lesson plans, and other items that will encountered in the PBL problems. Each team gets a different scenario.

Many students have searched for items on the Internet but not many have learned to use research databases such as ERIC, PsychLit, etc. The session mentioned above conducted by Alexius Macklin helps my students to overcome this. When students hand in their responses to PBL problems they attach copies of the web sites where they have conducted their research. Each member documents how he or she spent their time researching aspects of the problem. If the students encounter some web sites that may not be "truthful," I go over how to evaluate web sites using a resource put out by the University of Wisconsin—Eau Claire Library named the "Ten Cs." (http://www.uwec.edu/library/guides/tencs.html)

Purdue University faculty who use PBL have also come in to explain different aspects of PBL to my students. Since I am new to PBL, I do not profess to know everything. This has worked out well so far.

Peer Evaluation

In order for groups to have accountability, I have team members evaluate one another as well as themselves after every project, lesson plan, or PBL scenario that they complete. The peer evaluation form (found is the appendix of this paper) is what students fill out). Any group member who receives a failing grade on evaluation fails the course. So much group work occurs in the course that it must have this fail/safe component.

Introducing Problem-Based Learning to Methods Students

Problem-based learning is introduced to elementary science methods students by conducting the tower activity [described above] and debriefing it in terms of cooperating learning, the roles that they took on (process skills and state standards [science habits of mind] are also part of the discussion). This activity is conducted during the first class period of the methods course. The debriefing happens immediately after the tower activity.

The most important feature of any scenario, activity, or project conducted is for each and every methods student to develop their own perspective on important science education issues that include teaching lessons, managing science, etc. Since one of the main points of emphasis in the methods course is science pedagogy, I have students do the "What is PBL?" activity (found in the appendix section of this paper). This introduces PBL as an instructional model, introduces the central features of PBL, and gives the students time to conduct their own research. Students have found several wonderful PBL sites that I was not aware of.

Students use PBL to explore several important science education issues (curriculum adoption, why teach elementary science, and multicultural/gender issues). This work is conducted in groups. Students use the scenario assessment guidelines (found in the appendix section of this paper) so that they have some structure when doing PBL assignments and to model how I want them to document their response to the various science education scenarios.

The very first scenario or case study that I use concerns the nature of science. I use the "interrupted case method" to present the "*Its Not Easy to Be Green*" problem in three stages. The interrupted case method allows students to build their knowledge of a subject and discuss their opinions with their peers. The students also conduct research prior to class when that becomes necessary. It is important to keep in mind that students come to the science methods course with different science content knowledge and differing ideas about the nature of science. This PBL scenario sparks animated discussion about a current event that illustrates how science is conducted around the world. This three-part PBL problem can be found at the end of this paper.

Writing Problems

Articles that students are reading for the course seem to work well for writing PBL problems. I started by writing problems that were too "guided" and not open-ended enough. The Janice Cole scenario (found in the appendix of this paper) would be an example of this. Problems that are larger than having a single teacher as a character have been much more successful.

The gender/multicultural scenario is a wide-open problem for which students can develop differing perspectives. Guided problems seem to produce similar solutions and the students get bored very quickly listening to the same solution for each group that reports its results.

I have identified these major themes for the course:

- assessment
- adoption of science materials
- nature of science
- cooperative learning
- inquiry
- safety
- professional organizations

A problem is developed for groups to investigate on each one of the major themes. This has helped me to focus their attention and limit what I attempt during the course of the semester.

Hints for Writing PBL problems

The media can be a rich source for potential problems or case studies. Any media source can be used for this purpose. In the introductory course I have used newspaper articles on standardized testing, Ritalin, ADD/ADHD, teacher shortages, and other subjects. Other media sources have been TV news, practitioner publications (Science and Children, Science Scope, The Science Teacher, Instructor), and science publications (Science News).

A problem-based learning mindset is needed when you search for a problem. This means that the subject of the problem or case study has to be rich enough so that students can develop their own perspective on the issue. Some other criteria for finding a viable topic might include:

- Problem-based learning criteria: is the topic interesting and appropriate for you to use.
- The topic should act as a "hook".
- Media as sources of science/society issues.
- Goal is to choose appropriate materials that also have a hook.

An example of a problem that meets all of the above criteria is a problem entitled "It's Not Easy Being Green" (see appendix).

Lessons Learned

It was a personal decision to implement problem-based learning in my class all at one time. I thought about starting slowly and then it became clear to me that students would need practice working together in their group and would get better with continued PBL instruction.

In introducing PBL into my course I have had to drop other elements that I used to incorporate into the class. Something had to go but some of those things were the cause of my frustration to begin with. My advice to anyone incorporating PBL or case studies into their teaching would be to go for it! It has been easier for me to refine things having gone about it in this fashion. (You can see how I use PBL in my class by going to: http://icdweb.cc.purdue.edu/~jimmc/365index.html.) I don't claim to know everything about PBL, but I am always willing to learn. I can say without hesitation that teaching is more rewarding and fulfilling since I made the switch.

Epilogue

Since its inception, the problems that have been presented to the students via the Science Teacher Challenge have met the test proposed by Duch (1996). The problems are truly related to the "real world" because a member of it is standing right in front of them. Students are definitely engaged in the problem and motivated to resolve it because they are all preparing for a career as a science teacher. They enjoy working on problems that they may one day encounter when in the shoes of the people who have visited the class as part of the Science Teacher Challenge. The problems have also met Duch's test in that they are (a) open-ended, not limited to one correct answer, (b) connected to previously learned knowledge in other classes, and (c) although not "controversial" they do elicit diverse opinions. Finally, the students tend to work on, what Duch (1996) calls Level 3 problems (at Bloom's analysis, synthesis or evaluation levels) because (a) they must look beyond the text and do research to discover new material to help them propose a way to resolve the problem as they understand it, and (b) there is more than one acceptable answer to the problem.

One of the most incredible Science Teacher Challenges was the one that was done for a local school principal, in an elementary school located near Purdue University. The principal agreed to tell the students about the school. She then went on to tell the students that the school was having a difficult time finding exemplary science materials. The proposals were reviewed by the principal to establish their ranking (for grading purposes). Her comments as to why she ranked the proposals the way she did, along with the criteria that were used, were then faxed to the instructor. The principal then visited the class to present the results to an excited group of students.

An unexpected benefit of the Science Teacher Challenge actually occurred simultaneous to working on this paper. While preparing to conduct a workshop for educators to demonstrate how they could make their curriculum more relevant to their students through PBL. It was decided to cap off the workshop by having the attendees work on a problem using the Science Teacher Challenge template. The time and location of the workshop made it difficult to invite a manager from a local bakery to share a problem with the attendees to simulate how the Science Teacher Challenge is done in the sales class. A problem would have to written instead. The very idea of having to write a problem from scratch was dreaded due the amount of time it had taken to write problems in the past, which was the impetus for creating the Science Teacher Challenge in the first place. It was soon learned, however, that having been exposed to the presentations made by Science Teacher people in class, as part of the Science Teacher Challenge, made it easier for me to articulate a problem for the workshop. In fact, it was basically drafted in a matter of 15 minutes and finalized in 30 minutes; a task which used to take one to two hours when first experimenting with PBL two years earlier. In effect, the instructor of record had learned how to write problems as a result of observing the challenges that have transpired in the sales class over the last three semesters.

In conclusion, the mistakes of educators past must be corrected so that students improve their critical thinking, as opposed to short-term memorization skills -- PBL is truly one of the best ways to do it. This paper has catalogued a technique, known as the Science Teacher Challenge, which was developed to reduce the amount of time it takes to write a problem that can be digested by students via PBL. As it turned out, the means justified the ends for two very important reasons. First, the Science Teacher Challenge was a means by which students were presented with an opportunity to solve problems that they too may face one day. Second, the instructor learned how to write real-world problems in a fraction of the time it used to take prior to developing the technique.

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1. Understand the Nature of the Problem
   - a. How long has it been going on?
   - b. What factors are contributing to the problem?

   -People, Methods, Facilities, Money, Resources

   -Are these factors under the client's control?
2. What then is the problem?
   - a. Describe it in your own words
3. Do research to find out what others have done to solve the problem as you described it in step 2. Summarize what you have learned in a paragraph or two and be sure to cite references or sources.
4. Using the information gained in research and your own bright ideas brainstorm a list of ways the problem, as you have defined it, could be solved.
5. Do multi-voting to select the most viable means to solve the problem as you defined it. Show the votes.
6. Bring your case before the judge. Tell the client why the item you selected in step 5 will solve the problem as you have defined it!

Figure 1. Science Teacher Challenge Template

EDCI 365
Teaching Science in the Elementary School
What is PBL?

Purpose

The purpose of this assignment is to search the World Wide Web to find out more about problem-based learning. Use the links below to go to some sites that describe PBL and then search for some sites that are not included in the links below to add some information to what you have been able to find out.

Assignment

Write a 1-2 page typed paper about what you found out about problem-based learning. Be sure to address the following points in your paper:

- What is problem-based learning? How is it defined?
- How does problem-based learning differ from traditional methods of instruction?
- How is PBL constructivist in its philosophy?
- What is the role of the teacher in PBL?
- What is the role of the student in PBL?
- What other web sites did you find on PBL? What did you find out? (List the sites on a reference or works cited page.)
- What are your thoughts on PBL? How could you use it in your classroom? (Brainstorm and project. Choose a particular grade level.)

Links

Illinois Mathematics and Science Academy	http://www.imsa.edu/team/cpbl/cpbl.html
Samford University	http://www.samford.edu/pbl/pbl_main.html
Maricopa Center for Learning and Instruction	http://www.mcli.dist.maricopa.edu/pbl/problem.html
High Plains Regional Technology in Education Consortium	http://www.4teachers.org/projectbased/
North Central Regional Educational Laboratory	http://www.ncrel.org/sdrs/areas/issues/content/cntareas/science/sc3learn.htm
SCORE	http://score.rims.k12.ca.us/problearn.html

EDCI 365
Teaching Science in the Elementary School
Scenario Assignment Guidelines

What I expect your group to hand in for the scenario assignment each time you do it is the following:

Group Responsibilities

1. Each group should hand in a typed response to the scenario including their plan for researching the problem. The response is providing your answers to the following:

   a) **Stage 1**: Encountering and Defining the Problem
      i. What do I know already about this problem or question?
      ii. What do I need to know to effectively address this problem or question?
      iii. What resources can I access to determine a proposed solution or hypothesis?
      iv. At this point, a very focused Problem Statement is needed, though that statement will be altered as new information is accessed and understood. Write out your Problem statement.

   b) **Stage 2**: Accessing, Evaluating and Utilizing information
      i. Once they have clearly defined the problem, access print, human, or electronic information resources. Ask the following questions as you look at resources.
         - Part of any problem is evaluation of the resource. How current is it?
         - How credible and accurate is it?
         - Is there any reason to suspect bias in the source?
         - When utilizing the information, you must carefully appraise the worth of the sources they have accessed.

   c) **Stage 3**: Based on the research/brainstorming you have done, determine some alternatives that to the problem. List out each of your alternatives. Briefly explain each alternative.

   d) **Stage 4**: Delegate responsibility. Divide up the workload among the members of the group. Identify which group member will do what task.

   e) **Stage 5**: Select one of the alternatives. Present in a one to two page paper why you selected this particular alternative and tell your solution to the problem. Turn in one paper for the whole group. Please put the names of all group members on the front page.

Hand in two copies of the assignment and email your typed responses.

Individual Responsibilities

1. Each individual member of the group will hand in a typed one page or so summary of the work that they did on the problem along with documentation (printout of web pages, who you talked to on the phone, what you found in the library, etc.) Please put your name on this sheet. You need to do a thorough job on this. List the sources that you went to (citations for print sources, URL for web-based resources) and give reasons for choosing the resources that you did.

2. Attach this to the group response to the problem.

It's Not Easy Being Green

By Deborah Allen

(Based on presentation by F. Dinan and M. Hudecki at Annual Conference on Case Study Teaching in Science, 2000.)

Part 1

The first widespread use of DDT was in Italy during World War II-the clothing and bedding of allied troops and about 1.3 million civilians (including refugees) was dusted with DDT to control typhus spread by body lice. DDT offered promise as a safe yet effective insecticide with some saying "DDT will be the War's most significant contribution to the future health of the world.

Shortly thereafter, DDT was the insecticide of choice for many commercial agricultural applications, and since it was so highly potent as a contact insecticide, its potential in the control of mosquito-born malaria was soon recognized.

It was not until the 1960's that people began to publicly express concerns about the effect of DDT on the environment and its inhabitants, linking it to the death of birds and fish and other ecological disasters. DDT was banned in the U.S. in the early 1970's, and in other industrialized countries, it was gradually phased out in the mid to late 70's. Nevertheless, the World Health Organization (WHO) continued to endorse DDT for the control of malaria.

Discussion Questions:

1. What do you know about DDT, and why it caused such problems in the environment?
2. Why would the WHO continue to endorse the use of DDT?

It's Not Easy Being Green

Part 2

Environmentalists have never given up on the battle, however, to achieve a worldwide ban on DDT. "DDT is such a potent chemical that as long as it is used anywhere in the world, nobody is safe," said Clifton Curtis, director of the World Wildlife Fund's Global Toxics Initiative. "Because of their unique properties, POPs (*persistent organic pollutants*) pose a special kind of challenge that makes it impossible for any nation to remedy the problem by acting alone," asserts the WWF in public statement of policy on use of DDT and other chemical pollutants.

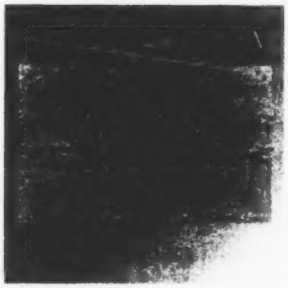
Now it appears that with the support of the United Nations and most major industrialized nations, environmentalists are nearing their long-standing goal at a time when malaria is re-emerging in most disease endemic countries. Beginning in the late 1990's, the United Nations Environmental Program (UNEP) has held a series to negotiate an international treaty that would lead to a legally binding global ban on the "dirty dozen" list of POPs, an environmental hit list that includes DDT. Would this ban, however, "reward First World environmental righteousness at the expense of the Third World," as many world health experts contend?

The issues that the UNEP must consider in negotiating a worldwide ban on use of DDT are complex, and are still the subject of hot debate.

Discussion Questions:
1. What issues need to be considered before banning DDT?
2. What groups would have an interest in deciding whether to ban DDT?

It's Not Easy Being Green

Part 3



On Sunday, 10 December 2000 diplomats and delegates of 120 countries approved a treaty allowing for the continued use of DDT in disease vector control. The delegates decided that DDT is a unique case, and whereas the other eleven environmental pollutants dealt with by the treaty were put on a list to be "prohibited or eliminated", DDT was relegated to a list to be "restricted". Countries wanting to use DDT would need to be registered on a DDT registry, and would be encouraged to develop and implement a plan for future action related to disease control and limiting use of DDT. The treaty also made provisions for an evaluation of the continued need for DDT for disease vector control (on the basis of available scientific, technical, environmental and economic information) at three year intervals.

Use the following questions to guide your preparation for the next class:

1. If you were the minister of public health in a malaria endemic country, what would you recommend for your country's plan for the control and/or eradication of the disease, looking 10 years into the future?
2. If you were the Secretary of the U.S. Department of Health & Human Services (or his equivalent in another industrialized country), what do you see as your fiscal or moral obligation, if any, to countries in which malaria is endemic?
3. If you were the Director-General of the World Health Organization, what malaria control strategy would your agency develop and endorse looking ahead 10 years?
4. If you were in a leadership role of an international environmental group, what action and/or recommendations would you make to the UNEP for future plans with respect to DDT?
5. If you were a parent of small children in a malaria-endemic country, what recommendations would you make to your country's decision makers?

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Reasons for Teaching Science in the Elementary School Scenario

Janice Cole is a new second grade teacher at Woodside Elementary School. Her principal has stressed how important it is for her to stress reading, writing, and math in her instruction to her students. The principal told her, "After all, these are the subjects that are covered on the standardized tests that we give in the spring. We want the students to do well on the tests." However, Janice likes teaching science and had some good experiences in her field experience for her elementary science methods class. She believes that science also needs to be taught. Janice wants to make a case to her principal and parents about the importance of science to her curriculum.

In your PBL group answer the following question: What do you think are reasons for Janice to teach science in the elementary school? Help Janice by coming up with some reasons for including science in her curriculum.

Steps to consider in your examination of the problem:

a) Define the problem as you understand it.
b) Do some research/brainstorming/talk to people to determine how you might solve the problem. Determine the key elements of their solutions.
c) Based on the research/brainstorming you have done, determine some alternatives that Janice has available to her.
d) Select one of the alternatives. Present in a one to two page paper why you selected this particular alternative and tell your solution to the problem. Turn in one paper for the whole group.

Deadline: Wednesday, September 10, 2001.

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Teaching Science in the Elementary School
Reasons for Teaching Science in the Elementary School Scenario
Assessment Matrix

Group members ____

Category	Well Developed	Acceptable	Poorly Developed	Not Addressed	Total
Definition of the problem. The problem is thoroughly identified and defined. Demonstrates that you understand the issues presented in the scenario.					
Research. Research documentation is attached to the scenario and each person in the group has shown what research they have conducted.					
Alternatives. After the research has been documented, alternatives have been outlined.					
Solution. The solution has been thoroughly posed and the reasons for choosing this alternative are clearly stated.					
Roles. Each person's contribution is clearly stated in the paper.					
General Appearance. Paper is complete, well organized, neat, and grammatically correct.					
Total					

Comments:

EDCI 365
Teaching Science in the elementary School

Gender/Multicultural Scenario

3. Now that you have read the Blake article, "Are You Turning Female and Minority Students Away from Science?" think about the following points and questions:

    1. The article was written in 1993. It had been hoped that research, legislation, and grants at universities and colleges that more female and minority students would want to become science teachers, engineers, scientists, or researchers. This is not yet the case.
    2. Is this a problem that needs to be solved?

4. Should this problem be solved? You have been appointed to a presidential commission to come up with some recommendations for resolving this dilemma. Your group is the education subcommittee of the presidential commission. What part should education play in this issue? What could elementary teachers do? Prepare a short report as a group to make recommendations to the President.

Follow the scenario assignment guidelines in the preparation of your response to the problem. There are both group and individual components of the assignment.

Deadline: Friday, October 12, 2001.

Peer Evaluation Form

Name ____________________________________ Group Name _____________________

This is an opportunity to evaluate the contributions of your teammates to group projects during the semester. Please write the names of your teammates in the spaces below and give them scores that you believe they earned. If you are in a group of five people, you will each have 40 points to distribute. You don't give yourself points. (If you are in a group of four, you'll have 30 to give away. In a group of three, you'll have 20 points, etc.) If you believe that everyone contributed equally to group work, then you should give everyone 10 points. If everyone in the group feels the same way, you will all receive an average of ten points. Be fair in your assessments, but if someone in your group didn't contribute adequately, give them fewer points. If someone worked harder than the rest, give that person more than 10 points.

There are some rules that you must observe in assigning points:

1. You cannot give anyone in your group more than 15 points.
2. You do not have to assign all of your points.
3. Anyone receiving an average of less than 7 points will fail the course.
4. Don't give anyone a grade that they don't deserve.

Group members

Score

1.

2.

3.

4.

5.

Please indicate why you gave someone less than 10 points.

Please indicate why you gave someone more than 10 points.

If you were to assign points to yourself, what do you feel you deserve? Why?

EXPLICIT/REFLECTIVE INSTRUCTIONAL ATTENTION TO NATURE OF SCIENCE AND SCIENTIFIC INQUIRY: IMPACT ON STUDENT LEARNING

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Judith Sweeney Lederman, Illinois Institute of Technology
Lee Matthews, Illinois Institute of Technology
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Introduction

Science educators have reclaimed the importance of educating to promote a scientifically literate society (American Association for the Advancement of Science [AAAS], 1993; National Resource Council [NRC], 1996, 2000; National Science Teachers Association [NSTA], 1989). Upon close consideration of the reform's vision for k-12 science education, one finds the emphasis extends beyond calls for students to have basic knowledge of scientific concepts and methods of scientific investigations. Understanding basic tenets about scientific inquiry (SI) and nature of science (NOS) are at the core of scientific literacy. In particular, the National Science Education Standards [NSES] (1996) states that "inquiry is central to science learning" (NSES, 1996, p. 2) and that "students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture" (NSES, 1996. p. 21). Research has shown that teachers typically lack views of NOS or knowledge about SI that are consistent with those advocated in reforms, and even our most expert teachers have difficulty creating classroom environments that help students develop informed views of NOS and SI (Lederman, 1992; McComas, 1998; Minstrell & van Zee, 2000). *Project ICAN: Inquiry, Context, and Nature of Science* is a professional development project designed to enhance middle and high school science teachers' knowledge and pedagogical skills that directly address the reform's call for student achievement in SI and NOS. Through continued teacher support, Project ICAN aims to enhance teachers' abilities to improve students' understanding of NOS and students' understanding of, and ability to perform SI, within a context of a standards-based science curriculum. Previous efforts have focused on either teacher knowledge or student achievement relative to SI and NOS. Project ICAN represents a first attempt to couple teachers' professional development relative to NOS and SI with an extended focus on teachers' classroom practice and student achievement. The purpose of this paper is to describe the effectiveness of Project ICAN on student achievement for year 1 of the project.

In efforts to foster scientific literacy in the classroom, teachers are asked to approach science instruction in a "constructivist" manner. Constructivist pedagogy is generally accepted as an approach that engages and utilizes students' existing knowledge in such a way as to build upon and/or reframe the existing construct to incorporate new knowledge. The focus in such a classroom is on helping students to understand, test, and revise their ideas; stresses the function of the social community in the negotiation of meanings and the growth of knowledge; and gives students increasing responsibility for directing important aspects of their own inquiry (Smith, Maclin, Houghton, & Hennessey, 2000). Research on teaching of NOS has demonstrated the effectiveness of a constructive approach with an explicit/reflective emphasis on aspects of NOS in relation to inquiry-based activities, historical examples, and even traditional school-science activities (reviewed by Abd-El-Khalick & Lederman, 2000). Similar results have been reported for learning *about* SI (Schwartz, Lederman, & Thompson, 2001).

Schwartz and Lederman (2002) proposed an emerging model of critical elements for the development of effective pedagogical content knowledge (PCK) for NOS and application of that knowledge in the classroom. Knowledge of NOS, knowledge of science subject matter, and knowledge of pedagogy are just three of the elements that blend to form PCK for NOS. However, the complexity of this blend is not well understood and is the subject of extended research. In addition to this knowledge base, teachers also need to express purposeful intentions to address NOS and SI within their classroom and maintain positive self-efficacy and outcome expectancy for their NOS/SI teaching efforts (Figure 1).

Research supports the claim that through purposeful and explicit/reflective instruction of NOS aspects and connections of aspects within the context of science activities that are familiar to students (both classroom-based and real-world examples), students are able to understand aspects of NOS as deemed relevant by the science education community (Abd-El-Khalick & Lederman, 2000; Carey & Smith, 1993; Khishfe & Abd-El-Khalick, 2000; Smith et al, 2000). Similar outcomes are suggested for learning about SI (e.g., Schwartz, Lederman, & Thompson, 2001). An explicit/reflective approach incorporates questioning and guided reflection to draw learners' attention to relevant aspects of NOS and SI in the context of inquiry-based activities or historical examples. These considerations of effective teacher development and classroom practice informed the design of Project ICAN.

Project ICAN: Design and Focus

Design

Project ICAN comprised a three-week summer institute followed by monthly workshops during the academic year. The summer institute focused on developing teachers' pedagogical content knowledge for NOS and SI (Schwartz & Lederman, 2002). There were thirteen teacher participants (8 middle, 5 secondary, and 1 middle/secondary). Teachers participated in sessions focusing on NOS, SI, and unified concepts through a series of explicit/reflective activities, readings, and discussions. In addition, teachers engaged in a science research internship with practicing scientists. This research experience was the subject of reflective journal writings and discussions designed to enhance teachers' understanding of inquiry and NOS within an authentic context. During the third week of the institute, teachers revised and practice taught lessons they would use during the academic year in their own classrooms.

During the academic year, teachers video-taped a monthly lesson, and collected lesson plans, reflections, and student work for project staff to review and provide feedback. Staff conducted on-site classroom observations to provide individualized feedback. A selection of video-taped lessons were presented to the group during monthly workshops, providing opportunities to discuss teaching contexts, offer peer support and feedback, and identify growth in their own and others' teaching. Teachers shared NOS and SI teaching experiences, discussed ways to further enhance lessons, and reported on student outcomes. Further details of Project ICAN summer institute and workshop activities are provided in another AETS 2002 session and paper (Lederman et al., 2002).

Focus: Definitions and Teaching Approach

Nature of Science

The "nature of science" refers to the epistemology of science, or science as a way of knowing. We acknowledge that there is not one single "nature of science" that fully describes all scientific knowledge and enterprises. There are various representations of NOS affirmed by historians, philosophers of science, science educators, and others, and it should also be noted that these representations are as tentative as the knowledge and enterprise of science itself. However, we contend that there is general agreement concerning certain aspects of NOS that are relevant and accessible to K-12 students.

Chief among these is that scientific knowledge is

- *tentative* or subject to change and revision.

Reasons for the tentative NOS stem from several other aspects including:

- scientific knowledge has basis in *empirical evidence*,
- empirical evidence is collected and interpreted based on current scientific perspectives (*theory-laden* observations and interpretations) as well as *personal subjectivity* due to scientists' values, knowledge, and prior experiences,
- scientific knowledge is the product of human *imagination and creativity*, and
- the direction and products of scientific investigations are influenced by the society and culture in which the science is conducted (*sociocultural embeddedness*).
- Additional important considerations to NOS include the differences between *observation and inference* in the development of scientific knowledge, and
- the differences between and functional roles of scientific *theories and laws*.
- These aspects are not mutually exclusive, but quite interdependent.

These aspects of NOS, although considered "science content," are relevant to the more "traditional" science content recommended for K-12 science education, and as such, *can and should be taught in conjunction with traditional science subject matter.* These agreed upon characteristics of the scientific enterprise provide a framework for teaching about NOS and SI and, in turn, describe what students should come to understand. Such understanding is a necessary component of scientific literacy. It is important to note that this list is neither all-inclusive nor discipline-specific, but represents those NOS aspects believed to be relevant to general K-12 science education and advocated in current reform documents.

Scientific Inquiry

As stated in the NSES, (NRC, 1996)

> "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries." (p. 23)

In addition to being able to conduct inquiries of various types, the NSES also promote students' understanding about scientific inquiry (NRC, 2000). This understanding includes

- knowledge about various methods of investigation (there is no single "scientific method"),
- understanding of the placement, design and interpretation of investigations within research agendas (current knowledge and direction guide investigations),
- recognition of assumptions involved in formulating and conducting scientific inquiries,
- recognition of limitations of data collection and analysis in addressing research questions,
- recognition and analysis of alternative explanations and models,
- understanding of the reasons behind the use of controls and variables in experiments,
- understanding of distinctions between data and evidence,
- understanding of relationships between evidence and explanations and the reliance on logically consistent arguments (based on historical and current scientific knowledge) to connect the two,
- understanding of the role of communication in the development and acceptance of scientific information

It is important to note that there is necessarily an overlap between the targeted aspects of NOS and aspects of scientific inquiry. However, even though NOS and scientific inquiry are interrelated concepts, they each need to be addressed explicitly. An understanding of one does not ensure an understanding of the other. The distinctions between NOS and scientific inquiry (or science process) need to kept clear. Conflation leads to reliance on implicit messages to teach one or the other.

An Explicit/Reflective Approach

An explicit/reflective approach to teaching NOS and about SI is emphasized throughout the program. An explicit/reflective approach to teaching NOS/SI is advocated and sought by the researchers as the desired approach to teaching about NOS/SI. An *explicit* instructional approach advances that the goal of improving learners' conceptions should be stated clearly and planned for, rather than be an expected outcome that relies on implicit messages. This approach intentionally draws learners' attention to relevant aspects of NOS and SI through instruction, discussion, and questioning. The term "explicit" should not be considered synonymous with "didactic." Explicit is used here to emphasize that teaching about NOS and SI should be treated in a manner similar to teaching about any other cognitive learning outcome. NOS and SI understandings should be intentionally planned for, taught, and assessed rather than be expected to emerge from teaching science content or process skills, or engaging students in science activities. The *reflective* component involves the application of these tactics in the context of activities, investigations, and historical examples used in daily science instruction. Thus, an *explicit/reflective approach* involves *purposeful* instruction of NOS and SI through:

- discussion;
- guided reflection;

- specific questioning;
- in the context of classroom science activities (including inquiry-oriented activities, examples from history of science, and traditional classroom-based science activities).

Data Collection and Analysis

Video-taped lessons, lesson plans, and classroom observations comprised the data for examining teacher NOS and SI teaching. Data were reviewed for explicit attention to aspects of NOS and SI. Student learning with respect to the targeted aspects of NOS and SI was assessed in a pre/post administration (beginning/end of academic year) of the Views of Nature of Science (VNOS-C for students) (Lederman, Abd-El-Khalick, Bell, Schwartz, & Akerson, 2001) and the Views of Scientific Inquiry (VOSI for students) questionnaires (Schwartz, Lederman, & Thompson, 2001). At least one class for each teacher was included in the analysis (around 800 students, grades 6-12). The NOS aspects assessed for students in Year 1 of Project ICAN include that science is a) tentative, b) based on empirical observation, c) influenced by subjectivity (both personal subjectivity and theory-laden observations/inferences), d) the product of human inference and creativity, and e) comprised of theories and laws. Aspects of SI targeted on the VOSI include a) multiple methods and purposes of investigations, b) importance of consistency between evidence and conclusions, c) multiple interpretations of data are possible, d) distinctions between data and evidence, and e) data analysis is directed by the questions of interest, involves representation of data and the development of patterns and explanations that are logically consistent. Other classroom assessments that specifically addressed NOS or SI were examined to enrich the description of student outcomes. Data for each student were analyzed to provide details of trends and shifts in students' views of the targeted aspects of NOS and SI. Class data were pooled to describe project outcomes. Although some percentages are approximated, specific quantitative data were not sought in this preliminary analysis.

Results

The primary purpose of this report is to describe trends and shifts in students' views of NOS and SI. Although reported here in brief, the impact of Project ICAN on teachers' knowledge of NOS and SI is the subject of another investigation (Lederman, et al., 2002). In general, 85% of the teachers demonstrated enhancements in NOS and SI views. These teachers varied in their instructional attempts and student outcomes.

Students' Pre-test Views of NOS and SI

In the interest of time and space, suffice it to say that the students in this study held pre-test views of NOS and SI that were naïve and realist. Students of all levels tended to view science as having "right" answers and finding the one true explanation of the world. This tendency was seen in student explanations of controversy in science (e.g. competing theories of dinosaur extinction). They viewed multiple interpretations as resulting from errors or incomplete data. Once all the data are collected, the answer is revealed. The students tended to view change in science as coming in the form of building upon existing knowledge (as opposed to change from shift in perspective). Regarding methods of science, students tended to view experiments in a broad sense. They saw all science as experiments because that is what one does in science. Examples of scientific experiments included simple frog dissection to "seeing what happens when you mix vinegar and baking soda."

Teaching Attempts and Student Outcomes

Eleven of the 13 (85%) of the teachers showed great improvement in their abilities to explicitly address NOS and SI within the context of Standards-based science subject matter. The monthly review of lessons, videos, and accompanying discussions demonstrated substantial growth from month to month. Teachers recognized their successes as well as challenges, and they shared their experiences openly with the group. Through the monthly workshops it became evident that the teachers had formed a peer support group where they valued their interactions and worked to progress together. Great efforts were made to establish and maintain a comfortable atmosphere wherein teachers were able to share concerns as well as success stories.

One of the teachers who showed no improvement dropped from the program half way through the year. The other teacher maintained fairly naïve views, but high self-efficacy. In other words, he thought he understood NOS and SI as well as how to teach these concepts, but assessment results and classroom observations indicated otherwise. Lacking recognition of his own weaknesses in NOS and SI conceptions and PCK, this teacher did not develop in the desired direction to the extent the other teachers did. Although he possessed a high self-efficacy with respect to his knowledge and classroom practice, the ultimate results in terms of student outcomes were far less than desirable, which was due to the lack of explicit integration of NOS or SI aspects within his teaching.

Nature of Science

Most commonly taught were aspects of observation and inference, subjectivity, tentativeness, empirical-basis, and creativity. Much less frequent was the difference between theory and law. Teachers reported ease of inclusion, or seeing where the aspect "fit" with their lesson, allowed them to explicitly address some aspects more than others. Additionally, their own level of understanding of NOS and SI and comfort with the subject matter and activity style reportedly influenced teachers' efficacy as well as method of teaching various aspects. For example, most easily taught seemed to be the difference between observation and inference. Similarly, this aspect seemed to be the easiest for the teachers to understand themselves and they saw frequent opportunities to express the distinction during their lessons.

Instructional approaches included didactic methods (simply telling students "science is tentative" or "It is important in science to back up conclusions with data.") as well as whole-group discussions within the context of a demonstration or an inquiry-based laboratory activity. Subject areas included generic NOS activities and content-embedded activities such as classification, natural selection, ecology, genetics, weather, and forces and motion. Details of teacher lessons are to be provided in a subsequent report.

Between 30% and 50% of the students whose teachers explicitly addressed NOS showed more informed views of at least one NOS aspect. The most significant changes in students' views were with respect to the inferential, subjective, and tentative aspects of NOS. Variance among classes correlated with teacher emphasis. For example, the teacher who seemed to teach observation/inference on almost a daily basis had students who used the words "observation" and "inference" in their post-test written responses as activities that scientists do and to support their claims for an investigation being "scientific."

> [Science is…] "*observatioins, inferences, models, dissections, how things in nature and animal life work.*"
>
> "*Scientists experiment and make observations and inferences.*"

In response to a question about whether or not the activity of looking at different birds and their food source to make conclusions about beak shape and preferred food is "scientific" or not, a student answered,

> "*Yes, because he took observations and inferences and made a description. Just like a scientist.*"

A notable change in students' views was in their acceptance of subjectivity in interpreting data. This NOS aspect necessarily overlaps with scientific inquiry's "valid multiple interpretations" aspect. Pre-test data indicated students tended to hold views in one "right" answer and any differences in conclusions were due to lack of sufficient data or errors on someone's part. Post-test data indicate a shift (almost twice as many post-test responses compared to pre-test responses) from this absolutist view that data are "all-revealing" to acknowledging personal subjectivity influencing data interpretation. Although a shift in the desired direction, many students presented an "anything goes" view that tended to see any conclusion as valid because people have different opinions and backgrounds. For example, when asked about how different interpretations are possible from the same set of data (given the controversy in dinosaur extinction as an example), responses included:

"They have different opinions."

"We all have different minds"

Some students did indicate their understanding of the inclusion of data in interpretations. These types of responses were considered indicative of more informed views of the empirical basis of scientific knowledge as opposed to an "anything goes" view.

> *"Everybody has different ideas about everything. They could come to different conclusions because they could interpret the information differently..."*
>
> *"[Different conclusions from the same set of data are possible because] they might put together the information different."*

Regarding tentativeness of scientific claims, students demonstrated mild shifts from realist views *("There is only one right answer in science.")* to indicate recognition of possibility of change in the future *("We don't know anything exactly. Everything changes")*. However, change was mostly due to new technology and new findings. At this point, scientific knowledge was seen as building on itself and is self-correcting.

> [Scientific knowledge may change in the future because…]
>
> *"Scientists will find new things and better explanations."*
>
> *"I think information will change because things change and scientists will come up with new theories and find more info out and will keep finding new things."*

Some students expressed change in terms of the world changing, not just our understanding of the world.

> *[Scientific knowledge may change in the future because…] "we will have new technologies and many new species."*
>
> *"I think it will change in the future because like if animals have offspring with different breeds the offspring will turn out different than usual."*

Few students exhibited more informed views with respect to the distinction between theories and laws. This aspect was rarely taught, even though most of the teachers had a firm grasp of the differences AND given the clear connection to the distinction between observation and inference. Teachers reported a lack of context for teaching about theories and laws. Those who taught physical science tended to make mention of theories and laws more frequently than those teaching life science. Yet, still little explicit attention to the distinction between theories and laws was provided. In general, students held two types of views. First, they had views of theories and laws as having different levels of "proof" behind them whereby theories are simply guesses and laws are proven true.

> *"A theory that we don't know if it's true or not. Example: In the year 2030, there is going to be a huge earthquake in Oregon. A law is something we know is true. Example: There was a big flood in Texas."*
>
> *"A theory is a guess and does not have a lot of facts behind it. Example: The dinosaurs were killed by a comet. A law is something that is proven by facts. Example: The dinosaurs died out."*
>
> *"A theory is what scientists guess on something. Example: dinosaurs. A law is a fact about an organism that is true. Example: How DNA works."*

Second, some students understood the terms in the everyday vernacular use and applied this understanding to science. For example, theories were guesses or possible explanations. Laws were "passed by scientists" and "rules that scientists follow." For example,

" A scientific law is a rule that scientist follow. Example: Wear an apron."

Some students demonstrated mild advances in their understanding of theory and law. Outcomes varied by teacher. Still less than 10% of the students indicated informed understandings of this aspect.

Scientific Inquiry

Eighty-five percent of the teachers, as compared to 30%- 45% of their students, demonstrated major changes in their views of SI during the course of the project. At the start of the program, most of the teachers believed that SI involves a set and sequence of steps that will objectively lead to one right answer. This is traditionally referred to as "the Scientific Method." During the project, most of the teachers came to acknowledge that there are multiple methods of scientific investigations. This realization was reflected in their teaching. One teacher expressed his view of scientific inquiry and the traditional way he used to teach as, *"The thing about the Scientific Method is it sucks all the humanity out of science."* This teacher changed the way he approached inquiry instruction in his 8th grade physical science class by encouraging students to be more independent in what and how they investigate. This teacher also incorporated more historical examples into his lessons. The majority of his students expressed an understanding of multiple methods of investigations and that science is a human endeavor, with room for "error" and interpretation. However, this teacher placed little explicit emphasis on any other aspects of NOS or SI. He assumed his students would come to understand the meaning of tentativeness of scientific knowledge and the role of subjectivity by learning about the historical cases he presented.

The teachers conducted several inquiry activities in their classrooms that were followed by explicit discussions of inquiry and NOS. About 40% of their students showed enhanced understandings of multiple methods of investigations. However, few were able to give concrete examples of differences. Again, grade level and subject varied. In response to the question about the bird beak investigation, students who demonstrated understanding of multiple methods tended to respond such as:

> *"Yes the investigation is scientific because he is trying to find out more about the birds. It isn't an experiment because he doesn't mix anything together and test it."*
>
> *"It is scientific because he makes observations and conclusions. It isn't an experiment because he doesn't test anything new."*

All teachers demonstrated more informed views of the multiple interpretations of a given set of data. However, only 60% of these teachers explicitly addressed this aspect in their classroom practices, although inconsistently. About 30% of the student exhibited more informed views of this aspect.

Question: If several scientists working by themselves ask the same question (for example, they all want to find out why volcanoes erupt), will they come to the same conclusions? Why or why not?

> *"No, because they could all have heard, learned, or know different information that would help them come to different conclusions."*
>
> *"No, they all have different minds."*

When asked if their response changes if the scientists are working together, a response indicative of considering the role of communication and conviction in science included:

> *"Yes, because then they could all give their view and understanding and reasoning on what they think and why."*

Some students maintained naïve views regarding data interpretation. They think that given the same data, scientists should come to the same conclusion. It is what we call a "seeing is believing" position. The data in effect *is* the answer for these students. Careful consideration of questions, analysis, and inference are not clearly acknowledged by students with this view. This view was typical of pre-test responses. Although up to 30% of the students showed enhanced understandings of subjectivity and valid alternative interpretations, this naïve view was still prevalent in many post-test responses. Examples of representative responses include:

> *"If all the scientists are using the same procedures to collect data, they most likely will come to the same conclusions if the get all the same data."*
>
> *"They are all looking at the same information so they would all get the same conclusion."*

To their credit, teachers recognized their instructional inadequacies regarding explicitly acknowledging alternative conclusions. They attributed their difficulties to lack of examples relevant to classroom investigations. This result is evident of simplistic inquiries where one general conclusion is likely. Lesson observations were thusly consistent. Teachers needed and wanted examples of data sets where more than one conclusion could be reached and accepted. This limitation was perhaps due to subject matter wherein teachers wanted students to reach one answer that was consistent with accepted scientific knowledge.

All teachers demonstrated more informed understandings of the role of evidence in supporting conclusions, and 85% of these teachers explicitly emphasized this aspect during instruction. Emphasis, however, was sporadic and context-dependent. Again, teachers had difficulty in recognizing opportunities to teach about this aspect within daily instruction. They reported having a set of questions to guide planned classroom discussions following laboratory activities wherein students collected data and formulated conclusions. Such discussions rarely involved all the students and time constraints limited extension beyond the classroom context. Students demonstrated somewhat more informed views.

Distinctions between data and evidence are often overlooked in the science classroom. Understanding the difference, that evidence is the data or pattern from the data that is useful in supporting one's conclusions, should be helpful for students in their understanding of the importance of connecting conclusions with evidence. Furthermore, making the distinction explicit in the classroom likely helps students with formulating arguments necessary to support their own conclusions. Pre-test responses indicated students either had no idea what data or evidence meant or they tended to use the terms as synonyms. Post-test responses indicated slight shifts toward recognizing differences between the terms and their purposes.

> *"Data is information. Evidence is something you can use to support a question."*
>
> *"Data is information. Evidence explains stuff."*
>
> *"Data is what you collect. Evidence proves something."*

Regarding data analysis, few students attempted to answer the question. Those who did indicated data analysis involved graphing or "looking at your data to find your answers."

The creation and use of scientific models and modeling was emphasized in Project ICAN and several teachers were able to include relevant explanations and discussions during the academic year. One teacher of grade 7 life science took an opportunity to discuss models during her lesson on natural selection. The activity involved students as "predators" and dots of paper of various colors as "prey" on various patterned fabric backgrounds ("environment"). Students did several rounds of "feeding" to determine the survivability of different colored "prey" in selected "environments." The teacher used this activity to discuss models and modeling in science. She asked students about the purpose of the modeling in explaining and making predictions about what happens in real world environments. Compared to pre-test data, post-test data contained more references to models in science.

> *"[Scientists] make models of what they are working on. Then they predict about it."*
>
> *"Scientists do experiments, study life and make observations and models."*
>
> *[A scientific experiment is] "studying of something using models and info they have researched."*

Conclusions and Implications

Overall, students' conceptions of NOS and SI showed some advancement. The results reported here are trends identified from preliminary analysis of student data. The extent of advancement and relationships among teaching styles, context, grade level, and conceptions have not been sought at this point. The approximated degree of advancement is not as compelling as we had hoped, but encouraging lessons were learned. Most advances were with respect to the inferential, subjective, empirical, and tentative aspects of NOS and multiple methods, multiple interpretations, and the difference between data and evidence. It appeared that these aspects were more easily integrated into teachers' classroom practices, as they reportedly "fit" more appropriately within a wide range of contexts. Students' views related to the distinction between theories and laws, the importance of connecting evidence with conclusions, and understanding of data analysis remained more naïve. These aspects proved to be more difficult to explicitly incorporate into daily instructional practice for the ICAN teachers. The transition from an absolutist "one right answer" view to one of "anything goes" has been reported elsewhere as a step towards a full transition to understanding the inherent tentativeness, subjectivity, and creativity involved in scientific knowledge (e.g. Lederman et al., 2000; Schwartz, Lederman, & Thompson, 2001; Schwartz & Lederman, 2002).

Results of this study are consistent with others reporting the myriad of factors influencing effective NOS and SI learning outcomes. The homogeneity of results from grade 6 through grade 12 suggests that grade level is not necessarily a constraint to effective NOS and SI instruction or learning. Teacher knowledge and teacher intentions are key. Those teachers who maintained naïve views of certain NOS and SI aspects were ineffective. Those teachers who held more informed views were not necessarily effective unless they secured these views within their own minds and intentionally within their instruction. Even so, these teachers reported difficulties with consistency throughout their subject matter. Those lessons that were revised during workshops held far more explicit references than other lessons. Comfort with subject matter, time, and features of daily teaching (schedule changes, management, absentees, curriculum constraints, etc.) all impacted teachers' abilities to revise and implement lessons consistently. As such, NOS and SI instruction was more sporadic in occurrence than presented as a unifying theme across the curriculum. These results support the model of necessary requirements for NOS teaching (and SI teaching) and PCK for NOS proposed by Schwartz and Lederman (2002).

One source of particular concern was in classroom assessment of NOS and SI. Often the teachers would include some explicit references to several aspects, but then make the assumption that these aspects were clearly understood by the students. In these cases, teachers asked few questions for clarification, and the explicit references were rarely followed up with discussions or examples. Teachers were not comfortable with assessing students' views in a formative or summative manner. Discussions would be valuable opportunities to formatively assess students' views of specific aspects and connections among aspects and subject matter. It seems for these teachers' first attempts, however, that they were more concerned with generating discussion than really listening and reflecting on student responses. Furthermore, teachers did not feel comfortable placing value on students' views with formal assessment methods. Part of their concern was their own struggle with the concepts. The teachers' views continued to develop during the academic year. The general feeling was, "How can I assess my students when my own views aren't solidified?" Rather than seeing an opportunity to understand their students better and, in turn, effectively respond to student needs, most of the teachers saw assessing NOS and SI as unfair. This feeling stemmed from their view that assessment places a "right" or "wrong" value on responses. Really, these results are not surprising given the novelty of the teaching approach and content. Reaching a comfort level with teaching and assessing NOS and SI that is conducive to effective instruction and assessment may require small steps toward success, with continuous support. Follow up workshops in coming years of Project ICAN will directly address the issue of assessment and teachers' concerns and perceptions.

Extended peer and professional support was an essential factor in Project ICAN to aid teachers in their development of NOS and SI understanding and pedagogical skills. Student outcomes are encouraging, although there is a lot of room for improvement. The proof will be in the sustainability of these teachers in the years to come to continue their efforts. Further research on progression of student views of NOS and SI and relationship to pedagogy and context is necessary to further advance our understanding of effective pedagogical practices.

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Managing Student/Teacher Co- Construction of Visualizable Models in Large Group Discussion

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This paper describes issues that have arisen in attempting to develop a markedly different approach to teaching biology at the middle school level. We have embarked on the development of a 7th grade curriculum titled "Energy and the Human Body" that deals with pulmonary and cellular respiration, circulation, and digestion (Ramirez, Clement, Nunez, and Else, 2001) . One of our goals is to address some of the conflicts teachers feel in responding to the call for both inquiry and conceptual understanding under the new national standards. Teachers often feel pulled in two different directions: on the one hand they are urged to teach content in a deeper way as measured by standardized tests; on the other hand they are urged to adopt student directed inquiry methods. They often feel that open-ended methods are incompatible with strong content goals that they are asked to fulfill.

The strategy used in our curriculum takes an intermediate position. The strategy is one of student-teacher co-construction that elicits student generated model elements as well as some that are introduced by the teacher (Rea-Ramirez, 1999; Steinberg & Clement, 2001; Clement & Steinberg, in press). I will further articulate this strategy and some of the issues it raises in what follows. Other aspects of the approach are described in Nunez, et al. (2002), and Else, et al. (2002).

Content Goals and Target Models

We are taking content goals seriously in this project, as reflected by our plans to attempt to measure conceptual change using pre and post tests during the curriculum trials. Content goals are expressed as descriptions of target models. Each target model is a desired knowledge state that one wishes students to posses after instruction. This may not be as sophisticated as the expert consensus model currently accepted by scientists. Instead of logical relationships used in formal treatments of the topic, an educator's view of the target model reflects qualitative, simplified, analogue, or tacit knowledge that is often not recognized by experts.

The curriculum must deal effectively with the problem that content goals in science are sometimes frustrated by the presence of student alternative conceptions (sometimes termed misconceptions) which are in conflict with the target model. However we also are alert for useful student conceptions that are compatible with current scientific models and that can be used as building blocks for developing the target model.

Van Zee and Minstrell (1997a,1999b) have discussed a number of strategies for promoting large group whole class discussion by drawing out students' ideas within the context of teaching for conceptual change in the presence of alternative conceptions. Hammer (1995) has documented some impressive thinking processes that can occur under such conditions in a secondary physics course. Further work is needed, however, on how large group discussions can feed model construction processes that are aimed toward content goals. Here I want to examine some different ways to describe some of the different roles teachers can play when they allow student ideas, both correct and incorrect, to be taken seriously in classroom discussions (where by 'correct' I mean largely compatible with the target model for the lesson).

Instructional Approach Used

The topics covered in our curriculum include digestion, pulmonary respiration, the distribution of oxygen and sugar by the circulatory system, and microscopic respiration in the mitochondria. The instructional strategies used include hands-on activities, analogies, discrepant events, model building, and computer generated animations, supported by scaffolding and probing questions. In this paper we will focus on a short example of the approach used in the *pulmonary respiration sequence* to illustrate some of the discussion leading decisions faced by the teacher.

Pulmonary Respiration Tutoring Sequence

A principle teaching method used to aid mental model construction is to have students invent models of body systems that could perform functions like breathing or delivery of nutrients to a limb. They are asked to do this on their own initially before receiving information from the teacher. Almost always this involves making drawings. The teacher then uses the students' initial models (including misconceptions contained therein) as a starting point to foster a series of model criticisms and improvements. Eventually enough changes are made to approach the target model for the lesson.

Figure 1 shows a typical part of the lungs teaching interaction. In an initial model constructed in a drawing by the students, the lung is mostly hollow (an incorrect "balloon" model of the lungs), with veins and many hairlike structures on the interior surface to "filter bad stuff out of the air." There is also a hole at the bottom of the lung. The teacher then asks a "discrepant question." "What is this hole at the bottom here? What would happen to the air there?" The students then begin to worry about air leaving the lung there and decide to modify their model by closing the hole. This is an example of an indirect and mild but focused intervention by the teacher. Some students think that the two parts of the lung might actually be joined together to in effect form one large cavity. At that point the teacher asks another discrepant question: "Are there operations where they remove one lung?" Students agree they know of such operations and decide that there must be two separate lungs.

Later when students realize the lungs are more "meat like" than "balloon like," they may make the air passageways too small or few in number to hold enough air. At that point the teacher sets up a breath measurement experiment where they use long plastic bags to measure how much air is contained in a deep breath, showing that there must be many pervasive tubes and passages indeed. Thus the discussion led by the teacher modifies the model in small steps, making it more and more like the target model for the lesson. In describing this process two aspects of Figure 1 are noteworthy:

CO-CONSTRUCTION IN PULMONARY SYSTEM

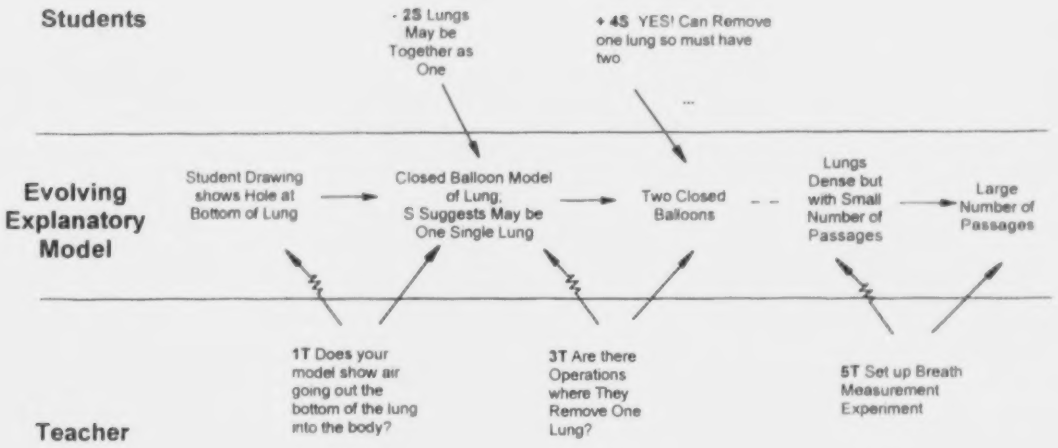
Students
- 2S Lungs May be Together as One
+ 4S YES! Can Remove one lung so must have two
...
Evolving Explanatory Model
Student Drawing shows Hole at Bottom of Lung
Closed Balloon Model of Lung, S Suggests May be One Single Lung
Two Closed Balloons
Lungs Dense but with Small Number of Passages
Large Number of Passages
Teacher
1T Does your model show air going out the bottom of the lung into the body?
3T Are there Operations where They Remove One Lung?
5T Set up Breath Measurement Experiment

Figure 1

- The sophistication of the students' explanations grew steadily during the instructional treatments. We can view the students' conceptual changes here as producing a sequence of

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progressively more expert-like models. This suggests a view of learning that has model evolution as its central feature, where students are able to build on knowledge that they had developed in earlier sections.

- Discrepant questions or events were used to motivate model revisions. These included the breathing capacity measurement. We modeled effects of the discrepant questions as internal dissonance with an existing conception. These are shown as jagged lines in Figure 1.

Distinguishing Between A Student Directed Agenda And Student Generated Ideas

We believe that part of the dilemma faced by teachers faced with both content goals and calls to use student centered inquiry strategies may be solved by increasing the precision of the vocabulary that we use to describe classroom interactions.

Two important but different ways to talk about student centeredness in a curriculum are the extent to which :

1. Activities are teacher or student directed (Who is setting the questions and the agenda?)
2. Ideas are teacher or student generated (Who is generating and evaluating the explanations and ideas in the learning?)

These are separate dimensions for describing a classroom but they are often confused. A way of describing the intent of the present curriculum is that it is teacher directed about 85% of the time--the teacher carefully directs the attention of the students to most topics and activities in a planned sequence. Thus it is quite teacher directed. Yet its ideas are teacher generated directly only about 40% of the time: within each topic students are encouraged to propose as many ideas as possible and then to modify and improve them, so that they may end up proposing

60% or more of the ideas. Thus the knowledge developed is largely student generated but at the same time the agenda is largely teacher directed.

This is a bit like the efficient structure of a meeting for an organization that has a chairman but that needs strong input from its members. The chairman sticks fairly faithfully to the agenda for the meeting, but opens the floor for input on each agenda item. Creative responses are encouraged. In addition the chair draws out or reminds the members of constraints that force reconsideration or modifications in some of the ideas that come up. This structure combines openness to ideas with the efficiency of an agenda that allows one to achieve goals and prevents aimless wandering of the topic. The structure contrasts to more dictatorial ones in that the members feel an investment in the outcome in that they have had an input to the process.

Thus, this puts the approach midway between pure "lecture" and pure "discovery learning", where by the latter I mean students inventing all the ideas without teacher input. The approach represents an intermediate position on whether ideas in classroom discussions should be teacher generated or student generated since it advocates both sources as important. In general, the aim is to have as many of the ideas be student generated as is practical, given the constraints of limited time for each curriculum topic. This serves the larger goal of fostering active learning and reasoning as a way to increase sense making, comprehension and retention. To do this the curriculum provides some guidance as to which ideas the students may be able to construct and which ideas usually require teacher introduction. Throughout discussions the teacher monitors the students' ideas, offering mild or if necessary, stronger support tactics to promote student construction until the next targeted model is reached.

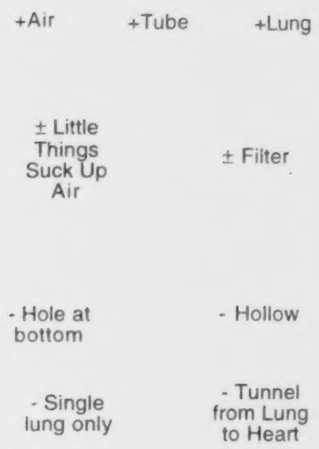
+Air
+Tube
+Lung
± Little Things Suck Up Air
± Filter
- Hole at bottom
- Hollow
- Single lung only
- Tunnel from Lung to Heart

Figure 2 Mosaic of Student Generated Ideas for Structure of Lungs

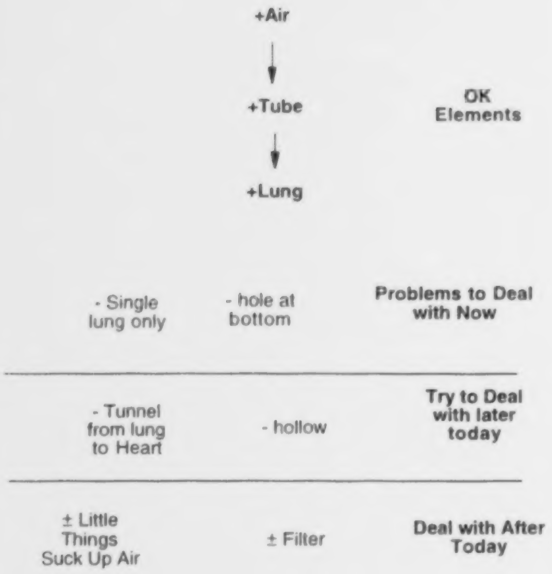
+Air
+Tube
+Lung
OK Elements
- Single lung only
- hole at bottom
Problems to Deal with Now
- Tunnel from lung to Heart
- hollow
Try to Deal with later today
± Little Things Suck Up Air
± Filter
Deal with After Today

Figure 3 Teacher's Agenda Organization of Mosaic of Ideas for Structure of Lungs

New Descriptive Images of Large Group Interactions

In this section I try to paint images of large group discussion that may help teachers think about their role in the process of student model construction. At this stage the following ideas are in the form of initial theoretical concepts formed in reaction to open ended classroom observations of curriculum trials. We plan to evaluate and refine these ideas in the context of more structured observations in the future.

The Mosaic of Student Ideas Generated by Large Group Discussions.

When students are encouraged to generate ideas in open ended discussion, a collection of unnervingly diverse ideas can be offered by students. The diagram in Figure 2 shows an example of what Maria Nunez calls a "Mosaic" of student ideas that the teacher is dealing with at any given moment. The Mosaic of ideas has the following features:

- The Mosaic outlines the present collection of "Ideas in the air" in the large group discussion.
- Some of the ideas are largely correct in the sense of being close to the target model. Others are largely incorrect, and still others are partly correct.

Key for Figures 2 & 3:

+ = Largely correct idea

- = Largely incorrect idea

± = Partially correct idea

To help steer their decision making within this somewhat complicated mix, teachers may impose an organization on these ideas in their own mind to help deal with them, as depicted in Figure 3, raising the following additional issues:

- There may be natural connections between the largely correct ideas according to biological structures or functions (as indicated by the arrows). These can form a rough initial model to work from.
- Teachers can sort the largely and partially incorrect ideas into 3 categories:
  Those we can work on now, work on later today, or work on after today.
- The last category implies that teachers can postpone dealing with certain misconceptions until students are prepared to deal with them. Rather than trying to immediately replace all of the misconceptions, the strategy aims at working on one at a time, and either modifying the misconception or replacing it.

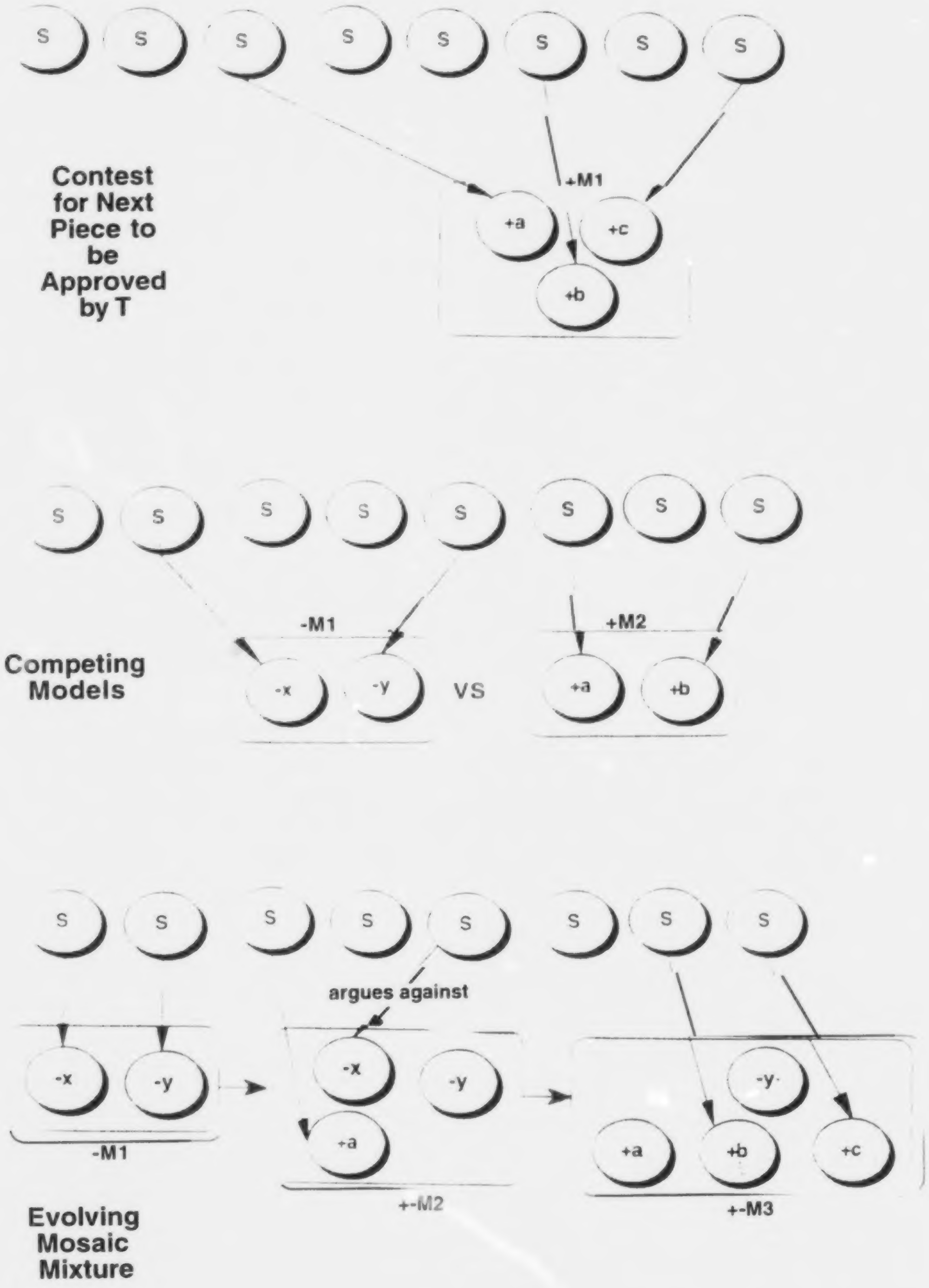
S S S S S S S S
+M1
Contest for Next Piece to be Approved by T
+a
+c
+b
S S S S S S S S
-M1
+M2
Competing Models
-x
-y
VS
+a
+b
S S S S S S S S
argues against
-x
-y
-M1
-x
-y
+a
+-M2
-y
+a
+b
+c
+-M3
Evolving Mosaic Mixture

Figure 4 Three Views of Model Construction in Whole Class Discussions

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Three Views of Large Group Model Construction in the Classroom

Figure 4 shows three modes of large group model construction patterns that have been suggested by classroom observations of our curriculum trials. These refer to large group discussions led by the teacher where the teacher is asking for ideas about the structure of the body, such as: "How does our body use the air we breathe to send oxygen to the cells?" or "How does blood get to the big toe to provide nourishment to it?" These questions are asked early in a unit before most students have studied anything about the topic, so there is an opportunity to elicit student preconceptions and creative model constructions. The overall approach is to present a function of the body (providing nourishment to the big toe) and ask students to construct a structure in the body that could perform the function.

Figure 4 uses the following key:

S = Student articulated idea

+a , +x = Largely correct idea

-a, -x = Largely incorrect idea

+M = Largely correct Model assembled from ideas as components

-M = Largely incorrect Model assembled from ideas as components

±M = Model that is partly correct and partly incorrect

The top portion of the figure represents a pattern where the teacher is selectively approving of only those articulated student ideas that are correct. He or she may then summarize or draw and add them to a collective model here labeled M1. Incorrect ideas are ignored. This is the most natural mode we have observed for the teachers to operate in, although we lean against using it very often because it can prevent meaningful discussion or comparison of models and elements.

The middle portion of Figure 4 represents a competing models pattern. The teacher recognizes both correct and some incorrect ideas as worth considering without passing judgement on them. These are clustered into competing models which can be drawn or summarized by the teacher. The teacher then solicits further discussion to foster student evaluation of the two competing models. The teacher may then have all students vote on the model they think is more viable.

The bottom portion of Figure 4 represents an evolving mosaic mixture pattern. Here a series of false to partially correct to more correct models are developed progressively, as was illustrated in Figure 1. Incorrect ideas form the first model M1 (although this has been oversimplified for the diagram; usually M1 would be a mixture of correct and incorrect ideas). Discrepant questioning on specific issues by the teacher may trigger student generated corrections or additions to part of the model to form intermediate model M2. This process continues to form more intermediate models until the target model is reached.

The aim here is to keep students in a "Reasoning Zone". Building on Vygotsky's ideas, I define the Reasoning Zone as an area of discussion where students can reason about ideas and construct new ideas productively (or at least contribute to its production in a group). Not all move in the direction of the target, but if thinking in the Reasoning Zone includes idea evaluation and modification, then progress toward the target should occur. If the question or topic chosen by the teacher is too large or too hard, it will be outside of this zone. This is what makes it important to utilize a strategic agenda as illustrated in Figure 3 to keep the students in a reasoning zone where they are able to make inferences and corrections to the growing model. Even so, sometimes when discussion starts it gets bogged down quickly. In this case the teacher attempts to provide just enough support in the form of a leading question, hint, new observation, reference to an earlier comment, discrepant question, etc. in order to get student reasoning going again.

Co-construction

The patterns shown are somewhat idealized in that all or most of the ideas are coming from the students and not the teacher. In practice some of the corrections may be made by the teacher in this process if specific content goals are a priority, a student correction cannot be elicited, and the teacher feels they are ready for it. Such patterns represent a process of co-construction in which both teacher and students contribute ideas and evaluations of ideas.

The curriculum we are developing is rich in visualizable models, therefore we believe it is important for the teacher to help students communicate with each other by drawing what students are describing (whether correct or not) on the board in front of everyone or having students draw their own models on the board. This provides a visual as well as a verbal communication channel to foster discussion. Drawings can then be modified to reflect modifications as the discussion proceeds.

Conclusions

All three patterns in Figure 4 are unusual in the extent to which they use student generated ideas. There is some danger that Pattern I can become a guessing game in which students throw out guesses to compete for the next piece to be approved by the teacher, without really evaluating the models themselves. Patterns II and III involve student generated evaluations as well as student generated ideas or model components. Pattern III along with a

Mosaic Agenda and discrepant questioning seems to be the most difficult to orchestrate and yet holds much promise as a pedagogical strategy. We are exploring the possibility that teachers can learn to orchestrate these patterns starting from pattern I and eventually working up to pattern III as they gain skills and practice.

We think it is important to examine the effectiveness of these strategies and the conditions under which each one may or may not be useful. In future research we think that tapes of large group discussions can be analyzed toward these goals. As we learn more about how to describe different kinds of classroom interactions that involve a large number of student generated ideas, we should be in a better position to recommend specific pedagogical strategies that respect the students' power to recall and generate useful ideas but that also take seriously specific conceptual goals in the form of target models .

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MAKING PUERTO RICAN HIGH SCHOOL PHYSICS CONTEXTUAL AND CULTURALLY RELEVANT: A STATISTICAL ANALYSIS OF INFLUENCING FACTORS

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Introduction

Since education is a rather complex interaction that takes place in a specific socio-cultural context (Pai & Adler, 1997), there are challenges to the premise that through education, modern scientific knowledge can be brought into other countries with little concern with culture (Cobern, 1999). Science education researchers suggest that most developing countries are using "superficial adaptations of essentially Western curricula" as their educational system (Cobern, 1999, p. 16). They also report that, if we want science education to be meaningful and effective, it must aggressively consider the cultural context in which the educational system in embedded, and the society which it will serve (Cobern, 1999; Wilson, 1981). However, the school systems of different countries reflect different social systems and cultures and hence have idiosyncrasies which may be unique, or at least not shared by the country whose curricula they may be importing. Such importation, therefore, can be fraught with the dangers of irrelevancy and impracticality if due attention is not paid to the differences, and similarities of the two social systems and cultures involved (Court 1972).

Historically, the structure and nature of science curricula in developing countries has followed closely that of their colonial forbearers, becoming not much more than a highly decontextualized and theoretical curricula (Gray, 1999). In the case of Puerto Rico, it was a colony of Spain from 1493 to 1898, and a colony of the United States from 1898 to 1952. Some scholars even argue that Puerto Rico is still a quasi-colony of the United States under its

Commonwealth status. As a consequence, the colonial educational system of both Spain and the United States, which by being colonial imply the explicit or implicit domination through "proselytizing the oppressed to believe that they do indeed belong to the positions and classes they occupy" (Pai & Adler, 1997, p. 45), have shaped and influenced the Puerto Rican educational system for more than 400 years. Even though Commonwealth status allows Puerto Rico to have an autonomous form of government, which makes decisions about the educational system, there is still evidence of the strong influence of the United States into Puerto Rican education (Eliza-Colon, 1989; Negron de Montilla, 1990; Solis, 1994).

Since the school and home experiences of Puerto Rican students are often quite different from the school and home experiences of other Latin American students, generic science textbooks translated from English to Spanish may serve as barriers to learning. Puerto Rican students' experiences will also be different from the school and home experiences of U. S. students, who were the original targets of the English version of the textbook.

A quick look at the translated high school physics book used in Puerto Rico provides several interesting examples of decontextualized topics and their lack of local applications:

1. The textbook introduces the metric system of measurement, however does not provide conversion factors to English units, which are more prevalent. I know by experience that, without some comparison between English and metric units, Puerto Rican students are unable to have a conceptual picture of, for example, how long a decimeter is, or how much liquid there is a dekaliter.
2. Forces and vectors are discussed in a dry, conventional way. Puerto Rico has many historical buildings with varied architecture, which can be used as illustrations of the interaction of forces in a structure.

3. The textbook has many examples of physics concepts using sports such as tennis, golf, or archery. Puerto Rican students are more familiar with baseball, basketball, boxing, or track and field. For example, students can videotape an athlete on the long jump, and then using physics to analyze the images.
4. Simple machines are explained well on the text, but local applications are missing. There is a place near Ponce, Puerto Rico, in which the flow of water near a river moves a series of pulleys, levers, and other machines in a coffee plantation.
5. The topic of energy will surely be more meaningful to students if they are able to research energy problems Puerto Rico faces, such as alternative energy production and the geographical realities of the island. For example, I remember reading about a project to develop a solar air conditioner at the University of Puerto Rico in Mayaguez.
6. In the textbook there are some pictures that are completely irrelevant to Puerto Rican students. On page 194 there is a thermal picture of a U. S. home with a discussion about residential insulation. However, in Puerto Rico houses do not use this type of insulation. On page 241 there is a picture of a road damaged by water freezing and thawing during winter. However, In Puerto Rico the temperature never reaches 0°C! An example of a closed bottle filled with liquid in a freezer is much more familiar to Puerto Rican students that a freezing road.
7. Puerto Rico being an island presents incomparable opportunities to study waves in a relevant way. In addition, the characteristics of sound can be fully explained using local music instruments, like "guiro" and "cuatro". The textbook missed those opportunities.
8. The textbook present examples of static electricity. However, most static electricity experiments do not work as well in Puerto Rico because of the air's high humidity. My

demonstration using a Van der Graff generator were much less impressive that the one on this textbook.

Research on the contextual and cultural relevance of the science textbooks used in Puerto Rican schools has not been performed, but when done it may provide evidence that these components, now somewhat missing in the physics classroom, might increase student achievement in physics, might promote a more positive perception of physics among students, and might even promote enrollment in high school physics courses. This might produce more educated and scientifically literate citizens in general, and will strengthen the science foundation for those students who plan to go to college.

Another reason for studying the contextual and cultural relevance of the textbooks used in Puerto Rican schools is in terms of the high school physics teachers. This and future research in this area might provide evidence in favor of supplementary teaching resources that consider the culture and context of the students in presenting physics concepts. It is expected that teaching physics with attention to these factors will be less difficult and more enjoyable for teacher and students alike. Teachers might also combine their experience and knowledge to become active participants in the creation of these supplementary materials.

The purpose of this paper is to report some of the findings of two months of quantitative data collection associated with the study of context and cultural relevance in physics teaching in Puerto Rico. First, we examined whether high school physics teachers use contextual and culturally relevant strategies in their classroom. In addition, we determined what factors influence the willingness of those physics teachers to modify their teaching methodology and physics curriculum so that the physics portrayed in the translated textbooks used in school become meaningful to Puerto Rican students. By meaningful, we mean contextual and culturally relevant to the Puerto Rican culture.

Methodology

Of the more than 120 physics teachers contacted during the eight-week period of data collection in Puerto Rico, ninety-two public high school physics teachers from the east and south of Puerto Rico participated in this study by returning the research instruments in person or by mail. These teachers were contacted by visiting their schools during the eight-week period of data collection in Puerto Rico. The participants were not randomly selected, making this a convenience sample. However, ninety-two high school physics teacher comprise about one third of the total population of interest, making this sample size undoubtedly representative of the total population of public high school physics teachers.

The quantitative portion of this study has three dependent variables and eleven independent variables. The dependent variables in this study are (a) the degree to which the Puerto Rican high school physics teachers modify the physics content presentation to make it more contextual and culturally relevant to the student population they serve, (b) the degree to which the Puerto Rican high school physics teachers modify their teaching methodologies to make them more contextual and culturally relevant to the student population they serve, and (c) the perceived degree of confidence in their physics knowledge.

In this study there are eleven independent variables, which are: (a) gender, (b) years of teaching experience, (c) years of experience as a physics teacher, (d) academic preparation in physics, (e) school size, (f) zone of school, (g) number of students per physics class, (h) perceived freedom to change the physics curriculum, (i) perceived freedom to change their teaching methodology, (j) perceived quality of the physics textbook, and (k) political beliefs.

The independent variables were chosen based on several criteria. One group of these variables can be called demographic variables and provide general information about the participants, which might or might not be related to the dependent variables of interest. Examples of demographic variables are the participant's gender, age, and years of general teaching experience.

A second group of variables were specifically selected based on the experience, preparation, and knowledge of the Puerto Rican education and culture of the first author. They were considered important and with a strong potential for a significant relationship with the dependent variables. Examples of these variables are the teachers' years of experience teaching physics, academic preparation in physics, number of students per physics class, perceived freedom to change the physics curriculum and their teaching methodologies, perceived quality of the physics textbook, and the teachers' political/ideological beliefs.

A third group of variables were included to support the validity of the study by producing non-significant results purposefully. Examples of these variables were school size and school zone. Based on the centralized procedures the Puerto Rico Department of Education use to place teachers, no difference was expected between teachers in urban, suburban, or rural areas, or from teachers from small, medium-sized, or large schools. Statistically significant results in these variables might have placed the validity and reliability of the instruments in question.

In order to gather the quantitative data, three instruments were developed by the researchers. The first quantitative instrument was the Textbook Relevance Degree of Change Instrument (TRI). It uses a Likert-type numerical scale (between 1 and 5) and an additional N/A option. The TRI is composed of 20 topics usually covered in a typical high school physics course (for example: motion, forces, momentum, gas laws, sound, light, etc.). The role of the teacher was to evaluate his/her degree of modification of those topics to make them more contextual and culturally relevant to their students.

In this instrument's scale, selecting "1" implied that the teacher did not make any modification in the way they present physics concepts discussed in the textbook to account for the characteristics and experiences of Puerto Rican students. On the other hand, selecting "5" implied that the teacher used examples with common materials and familiar situations, applied the physics concepts to problems of local relevance, included components of the Puerto Rican culture in the explanations, and connected the physics concepts with Puerto Rican realities. Intermediate numbers are assumed to represent a linear transition between the two extremes. The N/A option will be selected only if the teacher does not teach that particular topic in his/her class.

In addition, a section is provided for teachers to evaluate their degree of confidence of the different physics topics presented, which is the second dependent variable. This variable was also measured on a 1 to 5 scale, in which selecting "1" implies that the teacher is completely unsure (total lack of confidence) about his physics knowledge, "2" implies that the teachers is partially unsure (partial lack of confidence) about his physics knowledge, "3" implies that the teacher is undecided about his confidence in his physics knowledge, "4" implies that the teacher is partially sure/confident of his physics knowledge, and"5" implies that the teacher is completely sure/confident of his physics knowledge.

The second quantitative instrument was called the Teaching Methodology Degree of Change Instrument (TMI), created to measure the third dependent variable. It also uses a Likert-type numerical scale (between 1 and 5) and an additional N/A option. The TMI is composed of

19 common teaching techniques used by teachers in a typical high school course (for example: lecture, demonstration, laboratory, group projects, etc.). The role of the teachers is to evaluate his/her degree of modification of those teaching techniques to make them more contextual and culturally relevant to the needs, experiences, and particularities of their students.

In this instrument's scale, selecting "1" implied that the teacher did not make any modification in their teaching methodologies to account for the characteristics and experiences of Puerto Rican students. On the other hand, selecting "5" implied that the teacher adapted his teaching methods to include problems and situations of local relevance, used materials and equipment readily available in the community, and included components of the Puerto Rican culture. Intermediate numbers are assumed to represent a linear transition between the two extremes. The N/A option will be selected only if the teacher does not use a particular teaching technique in his/her class.

The third quantitative instrument was called the High School Physics Teacher's Demographics Survey (DS). It was created to gather information about the independent variables in a fast and efficient way.

One of the main purposes of quantitative research is to quantify variance and to separate it into different portions, which usually correspond to the independent variables of the study (Wiersma, 2000). In this case, one-way analysis of variance is used as the main statistical technique. Analysis of variance is an inferential statistical procedure used to detect significant differences in means for two or more populations or groups of people with different characteristics. It tests the null hypothesis that different groups' means (for a given dependent variable) are equal. The data available provided thirty one-way tests between the independent and dependent variables.

For this study, all possible efforts were made to maximizing its expected power within the limitation of the researchers. Diekhoff (1996) identified four main factors (choice of level of significance, choice of sample size, size of the effect of interest, and error variance in the population). Of those, we focused on the first two: choice of level of significance and choice of sample size.

When researchers adopt a liberal level of significance, they are making it easier for the statistical test to find significant differences, even if they are not that large. By increasing level of significance, we can increase the sensitivity of the test (power). Due to the nature of this study and the limitations of quantitative educational research, choosing a conservative significance level, like 0.01 or 0.001, is not recommended. Also, choosing a liberal significance level, like 0.1 or 0.2, is not a good option because of the number of univariate and multivariate tests performed and the risk of chance capitalization. As a way to both increase power and acknowledge the limitations of my study, a significance level of 0.05 was selected, although this significance level was considered somewhat flexible under special circumstances.

A difference of a given amount is more likely to be found significant if the researchers have a large sample size. A large sample size also reduces the sample variance. As a consequence, statistical tests are more able to recognize two variances as different. By increasing the sample size, we can increase the sensitivity of the test (power). During the first author's visit to Puerto Rico, he contacted as many teachers as possible to gather the largest possible sample size. At the end of data collection, the sample size consisted of 92 teachers, or about 1/3 of the total population of public high school physics teachers in Puerto Rico. Such a large proportion of participants out of the total population is an excellent indication that the study will be sensitive enough to make population generalizations.

Findings

For the following univariate tests, the statistical technique used was simple analysis of variance (ANOVA) to detect mean difference for the groups compared, with a confidence level of 0.05. In addition, the Levene test was performed to examine the assumption of homogeneity of variance. ANOVA works well even when this assumption is violated, except in the case where there are unequal numbers of subjects in the various groups. Since this is the case for some tests, a significant result for the Levene test will automatically discard that particular test. All the statistical analyses were accomplished using SPSS (Statistical Package for the Social Sciences), version 9.0.

Test 1 (S): Average Change in Physics Content Presentation as a Function of the Average Number of Students Physics Teachers Have in their Groups

Based on a sample size of 90 participants, the statistical analysis showed an overall significant relationship between the average change in physics content presentation and the number of students per class section ($F = 3.565$, $p = 0.033$). This result suggests that the larger the number of students in a classroom, the less change the teachers made in their content presentation (use of examples with common materials and familiar situations, application of physics concepts to problems of local relevance, inclusion of components of the Puerto Rican culture in their explanations, connection of the physics concepts with Puerto Rican realities). Interestingly, the post-hoc pair-wise comparison failed to identify any two means that are statistically different. Table 1 summarizes the descriptive data for this test.

Table 1:

Sample Size, Mean Change in Physics Content Presentation and Standard Deviations for the Number of Students Physics Teachers Have in their Groups

Students per group	Sample size	Arithmetic mean	Standard deviation
0 – 10 students	2	na	na
11 – 20 students	12	3.8398	0.8697
21 – 30 students	49	3.6354	0.1939
31 – 40 students	29	3.0403	1.1335

This test showed a significant relationship between the number of students physics teachers have in their class sections and the mean change they make to the physics content presentation to make it more contextually and culturally relevant, even after collapsing the first two categories into a single one to increase the statistical power of the test ($F = 3.898$, $p = 0.024$). This significant result suggests that the more students physics teachers have in their classes, another factor or factors associated with this increase affect the teachers' inclusion of context and culture in the physics class. As a consequence, less time is spent using examples with common materials and familiar situations, applying physics concepts to problems of local relevance, including components of the Puerto Rican culture in class, and connecting the physics concepts with Puerto Rican realities. In all cases, the mean change reported is more than three, which is indicative that even teachers with a large number of students per class are able to make some changes to their physics content presentation along more relevant lines.

Test 2 (S): Average Change in Physics Content Presentation as a Function of the Perceived Freedom of the Teacher to Modify their Teaching Methodology

Based on a sample size of 87 participants, the statistical analysis showed that there is not a statistically significant difference in the average change in physics content presentation across all categories (F = 3.073, p = 0.052). However, since the obtained p value is so close to the confidence level selected, plus the fact that 0.05 is nothing more than an arbitrary cutoff point, for discussion purposes this test will be considered significant. More detailed analyses, especially pair-wise comparisons among the means for the different categories, failed to identify any two means that are statistically different. Table 2 summarizes the descriptive data for this test.

Table 2:

Sample Size, Mean Change in Physics Content Presentation and Standard Deviations for the Perceived Freedom of the Teacher to Modify their Teaching Methodology

Perceived freedom	Sample size	Arithmetic mean	Standard deviation
No freedom	5	2.2922	1.0769
Some freedom	52	3.4905	1.1279
Absolute freedom	30	3.5755	1.0121

This test revealed that there is not a significant relationship, at the 0.05 confidence level, between whether teachers believed they have freedom to select and modify their teaching methodology and the reported mean changes in their physics content presentation to make it contextually and culturally relevant. However, there is a significant relationship at the 0.1 confidence level. In fact, the p value from the test is so close to 0.05 that it might be considered significant for discussion purposes. The reported mean for those teachers who think they have no say on their teaching methodologies (approximately 2.29) is very low compared to the reported mean for teachers who think they have some or all freedom in choosing and modifying their teaching methodologies (3.49 and 3.58 respectively). This is also consistent with the beliefs versus actions framework in the physics classroom.

Our experience is that the Puerto Rico Department of Education has no specific guidelines suggesting a group of teaching methodologies over others. Teachers, as education professionals, are left to judge and decide on the teaching methodologies that they want to use. However, we understand why some teachers think they have no freedom to modify their teaching methodologies. For one, public schools tend to be traditional, focusing on content coverage by lecturing, discussion and other teacher-directed means. In addition, it is easier, more objective and evidentiable (for legal purposes) to assess students on content knowledge by testing what was given by the teacher. Teachers might feel that they must (as opposed to "should") follow teacher-directed means of instruction.

Test 3 (S): Average Change in Physics Content Presentation as a Function of Teacher's Years of Experience Teaching Physics

Based on a sample size of 90 participants, the statistical analysis showed that there is not a statistically significant difference in the average change in physics content presentation across all categories (F = 2.410, p = 0.055). However, since the obtained p value is so close to the confidence level selected, plus the fact that 0.05 is nothing more than an arbitrary cutoff point, for discussion purposes this test will be considered significant. More detailed analyses, especially pair-wise comparisons among the means for the different categories, failed to identify any two means that are statistically different. Table 3 summarizes the descriptive data for this test.

Table 3

Sample Size, Mean Change in Physics Content Presentation and Standard Deviations for the "Years of Experience as Physics Teacher" Category

Yrs. exp. as physics teacher	Sample size	Arithmetic mean	Standard deviation
0 – 5 years	42	3.1558	1.1772
6 – 10 years	22	3.7798	1.0949
11 – 15 years	9	3.5981	0.9047
16 – 20 years	11	3.6631	0.7068
21 – 25 years	6	4.3022	0.7526
26 – 30 years	1	na	na
More than 30 years	1	na	na

This test showed that, although there is not a significant relationship at the 0.05 level between the mean change in physics content presentation and the participants' years of experience as physics teachers, there is a relationship at the 0.10 level. Since the p value for this test is so close to 0.05, I think it is worth mentioning, especially the appreciable difference in reported mean between novice teachers (approximately 3.16 for teachers with less than five years of experience) and veteran teachers (approximately 4.30 for teachers with 21 – 25 years of experience).

This difference between novice and veteran teachers might suggest that teachers learn to make their physics content presentation more contextual and culturally relevant from experience teaching physics classes, since the reported means started low at the novice level and keep increasing from the third category on. We do not have a good reason to explain why the reported mean for the 6 – 10 years of experience category is different from the overall trend.

To increase the statistical power of the test, the last three categories were collapsed into one new category (21 or more years of experience) and a new analysis of variance was performed. It failed to detect significant differences at the 0.05 level (F = 2.639, p = 0.054), but since the new p value is almost identical to the value obtained from the original test, the argument presented above is still valid. Since the obtained p value is so close to 0.05, and this confidence level is arbitrary, for discussion purposes this test will be considered significant. In general, these tests suggest that physics teachers do make changes to their physics content presentation, regardless of years of experience teaching physics, although there is a trend for veteran teachers to make more changes compared to novice teachers.

Test 4 (S). Average Change in Teaching Methodology as a Function of Teacher's Gender

Based on a sample size of 92 (48 males and 44 females), the statistical analysis found that the average change in teaching methodology for males was 3.99 with a standard deviation of 0.7812. For females, the average change in teaching methodology was 3.48 with a standard deviation of 0.9678. The difference in means between males and females was significant (F = 7.802, p = 0.006), which suggests that male physics teachers make more adaptations to their teaching methods to include problems and situations of local relevance, use more materials and equipment readily available in the community, and include more components of the Puerto Rican culture, compared to female physics teachers.

Since the academic preparation for becoming a science teacher might be similar for both genders, we theorize that factors related to their classroom experience are responsible for this difference, but there are no data to support this or any particular explanation for the significant result. Unfortunately, the data gathered do not provide any clues about this assertion; only future research might explore this topic more deeply.

Test 5 (S): Average Change in Teaching Methodology as a Function of the Number of Semesters of Physics Courses Teachers Have

Based on a sample size of 91 participants, the statistical analysis found no statistically significant difference in the perceived degree of confidence in the teacher's physics knowledge across all categories ($F = 1.658$, $p = 0.142$) when using the original categories. However, new statistical analysis with fewer categories found a significant relationship between these variables ($F = 3.050$, $p = 0.033$), which suggest that teachers who have taken more physics courses make more changes to their teaching methodologies compared to teachers who are less academically prepared in this subject area. Table 4 summarizes these new results.

Table 4:

Sample Size, Average Change in Teaching Methodology, and Standard Deviations for the Number of Semesters of Physics Courses Teachers Have (Collapsed Data)

No. semesters of physics	Sample size	Arithmetic mean	Standard deviation
0 – 2 semesters	24	3.2827	1.0796
3 – 5 semesters	29	3.9137	0.7668
6 – 11 semesters	23	3.9650	0.8425
12 + semesters	15	3.7817	0.5713

This test originally revealed that there was not a statistical relationship between the teachers' mean changes to their teaching methodologies to make them more contextual and culturally relevant and their academic preparation in physics. This finding is paradoxical in a sense, because one might think that subject content preparation and pedagogical preparation are two independent realms. Evidence of this is the fact that in Puerto Rico science teachers take their content area courses from the academic departments and their secondary or science pedagogy courses from the College of Education. We think that these last three tests do suggest that teachers must know their physics content in order for them to recognize a need to change. Teachers who are not well prepared in physics might tend to follow the text more closely and focus on covering the content without taking into consideration the local students' needs, experiences and interests.

Test 6 (S): Perceived Degree of Confidence in the Teacher's Physics Knowledge as a Function of the Number of Semesters of Physics Courses Teachers Have.

Given n = 89 participants, the statistical analysis revealed that there is not a statistically significant difference in the perceived degree of confidence in the teacher's physics knowledge across all categories (F = 1.669, p = 0.139). However, since some categories have few subjects compared to others, the original seven categories were collapsed into four categories to increase the power of the test and the statistical analysis was performed again. Table 5 summarizes the new descriptive information.

Table 5:

Sample Size, Mean Change in Perceived Degree of Confidence in Physics Knowledge, and Standard Deviations for the Number of Semesters of Physics Courses Teachers Have (Collapsed Data)

No. semesters of physics	Sample size	Arithmetic mean	Standard deviation
0 – 2 semesters	23	4.2406	0.6515
3 – 5 semesters	29	4.4057	0.5556
6 – 11 semesters	22	4.6508	0.3601
12 + semesters	15	4.6467	0.3868

The new analysis showed a statistical difference between the reported means (F = 3.126, p = 0.030), which state the obvious fact that teachers with less academic preparation in physics have less confidence in their physics knowledge compared to teachers with more physics courses. The fact that this obvious result was found provides evidence that the confidence scale is measuring what it was intended to measure. This might be considered a barometer test for this instrument.

In addition to the previous significant tests, four non-significant tests that showed definite upward or downward trends were noted. We think the mention of these trends is important for future replications of this study: (a) Test 4 (T): Average change in physics content presentation might be connected with the number of physics semesters teachers have, (b) Test 13 (T): Average change in teaching methodology might be connected to text quality as evaluated by the participants, (c) Test 22 (T): Perceived degree of confidence in the teacher's physics knowledge might be connected with the schools' geographical location, and (d) Test 23 (T): Perceived degree of confidence in the teacher's physics knowledge might be connected to the perceived freedom of the participants to modify their teaching methodology.

The rest of the tests were either non-significant or discarded because of heteroscedasticity of the data in an unequal cell size scenario.

Conclusion

The descriptive data for the independent variables provided insight and context about the participants' characteristics. For example, there was a remarkable difference between experience in teaching and experience in physics teaching. The result showed that most physics teachers are relatively inexperienced compared to their total teaching experience. Some possible explanations for this difference were stated. Also, it was found that one in four teachers have less than two semesters of physics, possibly a year of physical sciences or a year of general physics. The implications of this for teaching quality and the inclusion (or non-inclusion) of contextual and culturally relevant approaches in physics teaching are undeniable. If the 1:3 ratio is representative of all physics teachers in Puerto Rico, as we think it is, then there are a large number of teachers without the deep knowledge necessary to use a contextual and culturally relevant approach effectively in the teaching of physics.

It was also learned about the overcrowding of some physics classrooms and the effect this might have in the quality of teacher instruction, and about how most teachers appear to tailor the physics curriculum to the needs of their students, instead of following the physics curriculum prescribed from the Puerto Rico Department of Education. On the other hand, we saw teachers who think they have no freedom to change their teaching methodologies despite the fact that the Puerto Rico Department of Education leaves this decision to each teacher.

The descriptive information for the dependent variables is also enlightening. We saw how that, for the variable "average change in physics content presentation" the topics that are reported as made more contextual and culturally relevant changes, are usually those taught more frequently in the first semester of the course. Being taught more often, teachers have a good grasp of them and can make the changes. Overall, most of the reported means are larger than three, which suggests that teachers do make appreciable changes to their physics content presentation. For the variable "average change in teaching methodologies", the range of responses was broader, but most of the means are larger than three, which implies that teachers also made changes to their methodologies to make them contextual and cultarally relevant. Data from the third dependent variable suggests that a great majority of teachers feel confidence about their physics knowledge.

Results from the univariate test showed that the reported mean change in physics content presentation is statistically related to the teachers' experience teaching physics, class size, and whether they believe have freedom to change their teaching methods. Also, the reported mean change in teaching methodologies is statistically related to gender and academic preparation in physics. The participants' confidence in their physics knowledge was significantly related to their academic preparation in this area. Some of the tests that were not significant are also valuable as a validity tool because no significant relationship was expected and none was found. Some examples of these tests are those related to the schools' geographical location and school size.

It is clear that, based on the quantitative data, there are three or possibly four factors that determine if Puerto Rican high school physics teachers modify the physics curriculum to make it more contextual and culturally relevant to the student population they serve: (a) years of experience teaching physics; (b) class size; (c) whether teachers believed the Department of Education gave them freedom to select and modify their teaching methodology; and (d) academic preparation in physics. Also, there are two or possibly three factors that determine if Puerto Rican high school physics teachers modify their teaching methodology to make it more contextual and culturally relevant to local students: (a) gender; (b) academic preparation in physics; and (c) perceived textbook quality.

Limitations of the Study

Given the characteristics of the study, several shortcomings are apparent. In terms of the quantitative analysis, the sample size of 92 individuals was too small for more powerful tests, like two-way analysis of variance for all two variable combinations, to be performed. Unfortunately, replications of this study might face the same challenge given the number of

Suggestions for Further Research

Given the exploratory nature of this study, many questions were left unanswered. In general, further research should be done to replicate the findings from questions one and two, that is, confirm whether Puerto Rican physics teachers are making their physics content presentation and teaching methodologies contextual and culturally relevant. Special emphasis should be placed on the teachers providing specific, detailed evidence of how and why they make changes in these two areas.

Also, future research might focus on specific cultural aspects of Puerto Rico in the physics class, since the importance and relevance of this component was not completely detailed in this study. A more complex endeavor might be to explore the relationship between the concepts "culture" and context", and if these concepts are differentiable or not. This study identified a number of factors that might influence the teachers' decision of making their physics content and teaching methodology more pertinent. Each one of these factors can be explored in a different study.

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K-12 RURAL SCHOOL PRINCIPAL'S PERCEPTIONS OF SCIENCE REFORM

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Introduction

A Vision for Science Literacy

The National Commission on Mathematics and Science Teaching for the 21st Century (NCMST) released a report, Before It's Too Late, in September of 2000. Using results from the Third International Mathematics and Science Study (TIMSS) and the National Assessment of Educational Progress (NAEP) as evidence, the commission described in one word the current preparation that students receive in math and science as "unacceptable" (U.S. Department of Education, 1996; Harmon et al., 1997; NCMST, 2000). As the title of the Commission's report implies, the status of K-12 science education in the United States is in serious trouble and its improvement demands immediate attention – before it is too late.

The Commission's message of needing to improve science education is not new. Historically, there have been a number of reports that have sounded a similar alarm (President's Scientific Research Board,1947; U.S. Office of Education, 1953; NCEE, 1983). Bybee (1997) concluded in a historical review of science education reform that, "The past fifty years have witnessed only limited success in improving science education. Science educators have failed to transform purpose into practice, and they have also consistently underestimated the power of school systems and science teachers to maintain status quo (p. 24)."

Some have pointed out that there is not a single coherent vision to guide policies and actions for science in the United States (Schmidt, et al.1997). However, with the release of the National Science Education Standards (NSES) in 1996, the science educational community has moved closer toward a consensus regarding quality science teaching (NRC,1996; Texley & Wild,1997; NRC, 2000). According to the NSES, literacy in science means a person

> …can ask, or determine answers to questions derived from curiosity about everyday experiences...has the ability to describe, explain, and predict natural phenomena…[is] able to read with understanding articles about science in popular press and to engage in conversation about the validity of conclusions…can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed…[is] able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it…[has] the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (National Research Council,1996, p. 2).

Many states are now adopting or have adopted curriculum frameworks and learning outcomes for students in grades K-12. Kansas has based their science initiatives on the national science education standards. Although shorter, the Kansas Science Education Standards (KSES) define science literacy as

> …scientific knowledge and inquiry skills which enhance a person's ability to observe objects and events perceptively, reflect on them thoughtfully, and comprehend explanation offered them. (Kansas State Board of Education, 2001, p. 95)

The vision of science literacy set forth in the standards challenges the way science has been taught in the classroom. Science textbooks and teachers often emphasize the accumulation of facts and information in their definition of scientific literacy (Bybee,1997). For many, the main goal of science teaching is completing the text or covering the content in the syllabus (Gallagher,1996). Bybee (1997) explains that the expectation in the NSES is for teaching to move beyond informational lessons. Learning science means understanding the content and also developing the skills of inquiry. In similar fashion, the KSES recognize that inquiry "…is central to science learning" (KSBE, 2001, p. 2).

Science as Inquiry

Although the NSES do not recommend a single approach to teaching science, they do emphasize inquiry (NRC,1996). Historically and in many classrooms today, science is viewed as a body of knowledge learned through direct instruction (NRC, 2000). Marek and Cavallo (1997) note that even when students conduct labs that are called "experiments," too often they are not true experiments because the outcome is known in advance. These "experiments" are often called Inform-Verify-Practice (IVP) procedures. Using this procedure the teacher provides the students the science concepts or procedures. The learners then, have the opportunity to attach meaning to what they have been told by carrying out "experiments." Last, the students practice what they have learned by answering questions and solving text problems. "In a verification laboratory, students simply reenact with materials-apparatus, chemicals, living things- what the textbook tells them" (p. 4). This is not enough, it is only the beginning of science inquiry.

Both the KSES and NSES point out that "conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry" (NRC, 1996, p. 23; KSBE, 2001, p. 93). However, from this example it should be clear that standards-based science instruction means more than simply providing hands-on activities. It means engaging students in many of the same activities and processes that scientists do. For students this may mean they are involved in any or all of the following:

> …making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; … communicating the results…identifying assumptions, using of critical thinking, and considering alternative explanations (NRC, 1996, p. 23).

In other words, the goal of standards-based science instruction is not simply to verify or reinforce the facts about a science concept. Science instruction should help students develop the skills to do inquiry and a deeper understanding of the content. Butts and Hoffman (1993) provide insights into why providing hands-on activities is not enough. They state that even after instruction, learners have a tendency to retain incorrect ideas. Because of this, they argue hands-on activities must also engage the mind. They state that " …repeating similar hands–on experiences, exploring discrepant events, and discussing children's impressions and interpretations allows them time to cast off those comfortable, but incorrect ideas" (Butts & Hoffman, 1993, p.16).

Inquiry in standards-based science instruction also means that teachers do more than focus on developing process skills. It is essential that these skills be developed within the context of learning to do scientific inquiry, not in isolation. In essence, students should develop understanding and skills while involved in answering questions using logic and methodology similar to what scientists use. The KSES call this developing the "…abilities to think scientifically" (KSBE, 2001, p. 6). Below is an overview of the essential features of classroom inquiry.

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically-oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.

- Learners communicate and justify their proposed explanations. (NRC, 2000, p. 25).

Teaching science in this manner challenges teachers to view their role in a new manner. Rather than viewing teachers as "the experts whose role is to transfer the knowledge to students" (Lorsbach & Tobin,1992), the NSES advocate teachers lead students through inquiry experiences which "focus on the processes of doing investigations" (NRC,1996, p.121). For teachers, this means less emphasis "providing answers to questions about science content" and more emphasis on "students building and communicating scientific explanations" (KSBE,2001, p. 6). In this context, the teacher becomes a coach and engages the learner in constructing concepts and guides the scaffolding processes of the learner as part of quality instruction. Good and Brophy (2000) report Tobin as saying,

> …students are likely to miss the point of experiments or to fail to connect what they are doing and finding through experiments with major ideas developed in the curriculum unless their teachers explain key concepts thoroughly, prepare them for experiments by clarifying their goals and key questions, and structure and scaffold their work to make sure that they connect the big ideas" (p. 438).

These examples demonstrate the complexity and content specific issues involved in quality science teaching and learning. In order to teach standards-based science effectively, teachers will have to develop skills and strategies beyond those associated with direct instruction. Rhoton (2001) summarizes research on teaching strategies that support the goals outlined in the NSES. These strategies include

- Using inquiry and problem-solving lessons, active student participation, and frequent teacher-student centered interactions
- Creating learning environments in which risk is supported and open discussion and use of student ideas takes place

- Implementing lessons that provide an accurate portrayal of content knowledge, the nature of science, and the structure of the discipline
- Selecting and adapting curriculum to meet the needs of all students
- Implementing learning environments that challenge students' misconceptions
- Using discrepant events to facilitate student learning
- Using a variety of techniques to assess student learning.

For an overview on how the National Science Education Standards in this section align with the vision of science instruction in Kansas, see the complete set of Kansas science education standards at www.ksde.org/outcomes/science.

Moving the Vision into the Classroom

Unfortunately having a standards-based framework in place does not address implementation of these ideas into the classroom. Albert Einstein once said "...you cannot solve a problem by thinking in the same terms that caused the problem" (Hurd, 2000, p. 76). This statement is especially compelling when one considers educational reform in science. In the past, the focus of science reform was on how teachers were teaching rather than how students were learning. The high school edition of NSTA Pathways to Science Standards guide states: "For years we have been frustrated by the apparent contradictions in learning research. Results have shown that very different methods of teaching produce similar gains in learning" (Texley & Wild,1997, p. 8). The authors then assert that constructivist learning theory can explain this.

> ...the unifying principle of constructivism now explains why this is so. We now know that we cannot just transfer, or hand over, our own understandings of the natural world to our students. Instead as the Standards [the National Science Education Standards] point out, students have to construct or build their own knowledge in "a process" that is individual and social (Texley & Wild, 1997, p. 8).

Understanding student learning in this way does not imply that objective content knowledge is unimportant, but rather it underscores the importance of allowing students time and opportunities to accommodate new information.

This conception of how students learn will require teachers to examine their fundamental beliefs about learning. Jones (1997) summarizes the constructivist philosophy in the science classroom by saying,

> Constructivist philosophy alters the fundamental ways we view the teaching-learning process. The focus of a constructivist science classroom is on construction of meaning. This collaborative process involves the teacher, the student, and peers. The role of the science teacher is to facilitate and mediate the construction of knowledge. This primary role changes the traditional nature of the teaching process. It is not possible to "cover the curriculum" or "get through a textbook." These metaphors imply action that automatically results in "achievement." Instead, science classes are places for exploration, discovery, and building understandings. Laboratories no longer serve only to verify the contents of a lecture, but instead serve as rich environments where students develop ideas, experiments, and models that become springboards for new ideas, experiments, and models… (p. 141).

The NSES acknowledge that the most important resource a K-12 science program can offer students is a professionally competent teacher. Reports have indicated that the quality of teaching does make a difference in student achievement (Darling-Hammond, 1996; Haycock, 1998; NRC, 2001). Because of this, teachers are central to science education reform. After reviewing the research literature, the National Commission on Teaching and America's Future (NCTAF) reported "Studies discover again and again that teacher expertise is one of the most important factors in determining student achievement" (Darling-Hammond, 1997, p. 8). But getting practicing teachers to understand and embrace these new paradigms will not happen quickly or easily. Change takes time, and it is difficult (Fullan, 2001).

Rhoton (2001) states that, "Perhaps there is no greater challenge facing science education reformers than helping teachers move from current practices to strategies [consistent with the NSES]." Speaking from a teacher's perspective, Texley & Wild (1997) explain in part why some teachers may find change difficult.

> Our own view about the nature of science and learning-formed by how *we* were taught-affects everything we do. Changing theories and societal pressures can pass by our classroom doors with little effect if we have been so molded by our own educational history that we find it hard to change (p. 7).

Stating this in another manner, Rhoton et al. (1999) explained that in many cases standards-based science reform asks teachers to teach in ways they probably never experienced as students.

However, if standards-based science reform is to occur, current beliefs and practices must be challenged. Rhoton et al. (1999) summarized how far reaching changes have to occur if teachers are to strengthen their teaching practices to align with the NSES. Citing Nelson and Hammerman (1996), he stated teachers

> …must be willing to make a paradigm shift in their beliefs, knowledge, and teaching practices. They must be able to rethink their notion about the nature of science; they must be willing to develop new views about how students learn; they must construct new classroom learning environments and create new expectations about student outcomes (p. 1).

Professional Development

For teachers currently in school systems, professional development will have to play a major role in this change process. Unfortunately, the Committee on Science and Mathematics Teacher Preparation reported that "too often [professional development] consists of a patchwork of courses, curricula, and programs and may do little to enhance teachers' content knowledge or techniques and skills needed to teach science effectively" (NRC, 2001, p. 33). Rhoton (2001) agreed and reported that much of the professional development available to science teachers consist of short after-school meetings and stand alone workshops that are not connected to the realities of the classroom.

One reason for this is may be that the same research-based learning principles that are important for student learning are not taken into consideration when dealing with teacher development. In short, the issue of developing a deep understanding of content and concepts is as viable a concern for students in the science classroom as it is for teachers learning to teach science. Loucks-Horsley, et al. (1998) explain that,

> Experiencing learning in ways that hold to constructivist principles is the only way for teachers to understand why it is important for their students to learn in this way and for them to break their old models of teaching (p. 39).

Lessons from past failures indicate that true reform cannot simply consist of trying to develop teachers. Fullan and Hargreaves (1992) label this old view of reform as the innovation-focused period of teacher development. They summarize it as believing "successful change involves learning how to do something new." The road to improved science education is much more complex. As schools move toward developing curricula and instructional practices that are consistent with the NSES, it is true that" many teachers may need to modify their science materials and their delivery of these materials" (Barman,1997, p. 155). However as early as 1992, Fullan and Hargreaves stated

> Teacher development must be conceptualized much more thoroughly than it has been. Its relationship to educational change is not just a matter of better implementation of selected innovations (although it includes this) but more basically a change in the profession of teaching, and the institutions in which teachers are trained and in which they work. Teacher development is thus tantamount to transforming educational institutions.

Clearly, a narrow reform agenda that focuses only on the science teachers neglects the larger critical issue of the simultaneous transformation of the learning environments available for teachers in their local schools.

The NSES recognized this by not only outlining professional teaching standards to help guide quality instruction, but by also outlining the support systems necessary at both the program level and system level (NRC,1996). In similar fashion, the Glenn Commission identified seven key stakeholder groups as being critical to the improvement of student achievement in science. These stakeholder groups include the school board and superintendent team, principals, teachers, parents, state leadership, higher education institutions, and business (NCMST, 2000).

A Principal's Role

Fullan (2001) discusses the extensive research evidence that has pointed to the importance of the principal in improving teaching and learning in their school. One of the reasons for this may be that they are such an integral part of so many aspects of the school. In an overview describing the principal's involvement in school programs, Cunningham and Cordeiro (2000) wrote

> Generally these duties [of the principal] include administering all policies and programs; making recommendations regarding improvements to the school; planning, implementing, and evaluating the curricular and instructional programs; hiring, coordinating, and developing staff; organizing programs of study and scheduling classes; maintaining a safe school environment; providing stewardship for all school resources; and providing for co-curricular and athletic activities (p. 137).

In the case of rural school principals, the level of involvement is magnified. Recounting his personal experiences, Buckingham (2001) suggests that the job description for a rural principal is" …be everything to everybody all the time." This means the "…the rural principal is personally involved in not only every facet of the school, but the community as well."

Coble and Koballa (1996) document " …the need for a more holistic look at science reform." (p. 480). One way to accomplish this is to ascertain varying perspectives on educational issues from individuals involved in education like principals. Referring to the rural principalship, Buckingham (2001) stated "… Doing these jobs has given me a deeper knowledge not only of my building, but my students and staff." Because rural school principals possess intimate knowledge of almost every aspect of their school, they are in a unique position to provide important clues to assist in understanding aspects of science reform in Kansas.

Research Study

This study focuses on three areas related to the Glenn Commission's report. These include: a) reasons for science inclusion in the K-12 curriculum, b) principals' perceptions of a need for improvement in science education, and c) policies and practices that effect the quality of science instruction within schools.

The first area deals with the question of why science has been included in the K-12 school curriculum. Over the past 100 years, science has come to be an accepted element of the curriculum. The Glenn Commission summarized four important reasons why children in the United States need to achieve competency in mathematics and science:

1) The rapid pace of change in both the interdependent global economy and in the American workplace requires both mathematics and scientific skills;
2) Citizens need both science and mathematics for everyday decision-making;
3) Mathematics and science are linked to the nation's security interests;
4) A deeper, intrinsic value of mathematical and scientific knowledge shapes and defines our common life, history, and culture.

DeBoer (1991) stated that "justifications for teaching science affect what kind of science is taught and the ways in which it is taught (p. 216)." If this is true, valuable insights will be gained by investigating principals' perceptions as to why science is part of their school's curriculum.

The second area of the study deals with principals' perceptions regarding the need for the improvement of science education in schools. Need is an important factor related to the implementation of an innovation like the NSES (Fullan, 2001). This concept goes beyond recognizing there is an unmet need. As Fullan (2001) states, "schools are faced with overloaded improvement agendas. Therefore, it is a question not only of whether a given need is important, but also of how important it is relative to other needs" (p. 76). Fullan (2001) also identifies the principal as the "gatekeeper" of change, often determining the fate of innovations coming from the outside or from teacher initiatives on the inside" (p. 59). If this is true, the fate of reform in science education may well be influenced by the principal's perception of need.

The last area addresses the broader issue of policies and practices within the system that effect the quality of science instruction in a school. The Glenn Commission developed questions based on critical issues that have a direct influence on teacher quality. These questions include such things as opportunities to collaborate with other teachers, access to a knowledge base on science teaching, and teacher induction programs. The questions were targeted specifically at the following stakeholder groups: the school board and superintendent team, principals, teachers, parents, and higher education institutions (NCMST, 2000). Obtaining principals' perspectives on these issues may provide those concerned with science education reform fresh ideas about the dynamics involved ensuring teacher quality in science education.

Study Objectives

The questions that guided the study were: 1) What reasons do small and rural school principals in Kansas provide for the inclusion of science in the public schools curriculum? 2) Do these principals perceive a need to improve science education in their schools? and 3) What are these principals' perceptions concerning the critical issues surrounding science teacher development identified by the Glenn Commission for each stakeholder group?

Participants

This pilot study was conducted using K-12 principals from twenty-five rural schools that were geographically located around a land grant university in a rural mid-western state. School size varied from 53 to 470 students. Participants of this study were selected based on proximity, however future plans are to expand the study to include both science teachers and principals from throughout the state.

Data Collection

Using recommendations from Weisberg, Krosnick, and Bowen (1996) a self-administered survey was developed. The survey consisted of Likert scaled questions followed by space for comments. In addition to the Likert items, open-ended questions were also utilized. The Likert scale ranged from 1 to 5. For example response categories might include 1 (very difficult), 2 (difficult), 3 (neutral), 4 (easy), 5 (very easy) or 1 (definitely not a priority), 2 (not a priority), 3 (neutral), 4 (slight priority) and 5 (definitely a priority). The phrases accompanying the 5 point scale were modified for each question. Before administering the instrument, it was reviewed for content validity by three principals, two experts in science education, and one in educational leadership. Any items that were identified as unclear, inappropriate, or unrelated to the study were edited and where needed, items were added and deleted.

After this process, the surveys were mailed along with a cover letter explaining the purpose of the project. At approximately two weeks intervals, two additional follow-up mailings were sent to participants that had not yet responded.

Survey Response Rate

The questionnaire return rate for this study was 84%; 21 of the 25 mailed were returned. Weisberg, Krosnick, and Bowen (1996) report that response rates for mail questionnaires tend to be between 10% and 50%, therefore the response rate for this study was considerably higher than this estimated value. With the exception of question six in section one (60%), the response rates for individual questions ranged from 80% - 84%. While still above the estimated value, the lower response rate for question six may be attributed to the fact that it was an open-ended question that required more time to complete.

Participant Background

Nine of the principals in this study (43%) had between 2 and 4 years of experience as a school administrator. With the inclusion of six that had 5-10 years of experience, it becomes evident that almost 3/4 of the principals (71%) responding to the questionnaire had at least a moderate degree of experience at this position.

Data Analysis

Because of the small sample size (n=21), quantitative data from this survey were analyzed using descriptive statistics such as frequency counts and means to look for trends within the sample. Since this study was exploratory in nature, the data were further separated and analyzed to discern similarities and differences between each of the following sub-groups based upon grade levels: elementary K-6 (n=11); middle school 5-8 (n=5); high school 9-12 (n=6). Note that the total of each sub-group combined is greater than 21. This occurred because one K-8 principal responded separately as both an elementary and middle school administrator. One 7-12 principal did not differentiate answers according to sub-groups so this response was included in the 9-12 category. (See Appendix A for the complete set of quantitative data)

The qualitative data from the open-ended questions were inductively analyzed using an interpretive framework. Responses were collected and organized according to grade level: elementary, middle school, and high school. Comments of principals at each grade level were reviewed several times by the researcher to look for key words and phrases representative of the emerging categories. These were then clustered by similarity of interpretation to develop category titles. After further review, these categories were then expanded or collapsed and relationships between categories were sought. Enumeration relating to the frequency in which the key words and phrases occurred in each category was then used to establish major and minor categories. Themes were then allowed to emerge from these categories. To enhance the credibility of these qualitative findings, an outside researcher in science education was used to confirm the categories and themes that emerged from the data.

Findings

These results are summarized according to the three research questions that guided this study.

Research Question 1

What reasons do principals provide as to why science is included in the public schools curriculum?

Principals were asked to respond to an open-ended question (see survey question 1 below). Using inductive techniques to analyze, code, and categorize the principals' responses, the researchers identified 4 core categories. (See Table 1.) The researcher then determined the distribution of these categories across each of the three grade levels. (See Table 2.)

Survey Question 1: List at least one, but no more than three, important reasons why science is part of your district's curriculum.

Table 1

Core Categories of Principals' Responses to Survey Question 1

Category 1: Life Skills/ Life Long Learning	Participant Responses
• Science is a way to prepare students for the future and take an active role in the democratic process (Glenn Commission Report). • Science is "… a vehicle to prepare all students as lifelong learners who can use science to make reasoned decisions, contributing to their local, state, and international communities" (KSBE, p. 2).	"Science is used in daily life" "Life Skills – Preparation for becoming an active, informed citizen" " It prepares them for the future."
Category 2: Understanding the Natural World	
• Science relates to the natural desire of humans to know and understand. • "Through science teaching the natural world could be made understandable to all who were interested in studying it. It is natural for them to want a fuller understanding of the world around them, and education can assist in this process" (DeBoer, 1991, p. 220).	"Understand the function of nature" "Students learn how incredible the world around us is and the natural order of how and why things happen" "Create an understanding of chemicals, the earth's elements and relationship." "Science introduces the basics of our world. It allows students the opportunity to explain who and why we are."
Category 3: Extending Mental Abilities	
• As a discipline, science is unique in that it allows one to study the natural world and using ones mental abilities, make conclusions based on these observations. • Mental abilities include problem-solving, critical thinking, the ability to reason, and creative thinking.	"Teaches higher level critical thinking skills. " "Students learn how to solve problems through scientific (data driven) methods;" "Students need to be able to solve real world problems, and science is ideal for providing these."
Category 4: Outside Expectations	
• Science needs to be taught in order to meet the expectations of some entity outside the physical boundaries of the school. This includes such things as state exams, college admissions, or employment needs of businesses.	"Qualified admissions requirement for Board of Regents" " State Assessments" "Important for those going into science programs in college and careers."

Table 2

Distribution of major and minor categories at each grade level

Elementary	Middle School	High School
Major Category: Life Skills/Life-Long Learning (6); Extending Mental Abilities (6)	Major Category: Extending Mental Abilities (3); Understand the Natural World (3)	Major Category: Extending Mental Abilities (4); Understand the Natural World (4)
Secondary Categories: Understand the Natural World (3)	Secondary Categories: Life Skills/Life Long Learning (1)	Secondary Categories: Outside Expectations (3); Life Skills/Life-Long Learning (1)

Note: the number in brackets ( ) indicates how frequent phrases in each category occurred.

Notice the two major categories for elementary principals are "Extending Mental Abilities" & "Life Skills/Life-Long Learning." These categories are reflective of the Glen Commission Report and the need for increased science achievement. Elementary principals in this study view the role of science in the curriculum in the same light as the Glenn Commission: to prepare students via knowledge and skills for the global workforce and for daily decision-making. Both categories are consistent with an inquiry-based teaching approach.

It should be noted that "Extending Mental Abilities" is a major theme across all three grade levels. This implies that principals are aware of the important role science can play in developing students' creativity and critical thinking skills. This raises the question as to how the Inform-Verify-Practice model, which focuses on the acquisition of content, has managed to maintain its high profile status in the science classroom. One explanation could be that other competing reasons cause educators to compromise this aspect of science for what may be seen as other viable goals.

At the middle and high school level, "Understanding the Natural World" joins "Extending Mental Abilities" as a major category. "Understanding the Natural World" suggests, as does the Glen Commission report, that increasing science achievement develops the intrinsic value of the discipline to our lives, culture and history. What is interesting is the shift by these principals away from the broader, more holistic reasons suggested by the "Life Skills/Life-Long Learning" category, to phrases that suggest a focus on the direct application of the content. This is consistent with what one would expect. Subject matter specialists teach middle and high school science as a separate discipline, therefore one would expect an approach to science teaching that emphasizes the direct application of content. However, in doing this, it is important those educators at this level not neglect the broader, more holistic reasons suggested by the "Life Skills/Life-Long Learning" category.

Both major categories in the middle school continue into high school. However, it is important to note a new category emerges - "Outside Expectations." This category suggests an additional influence at the high school level that is not present at the other two grade levels. The reasons for teaching science now take into account the immediate plans of the student; this includes preparation for college.

DeBoer (1991) described how historically science has been taught as both a product and as a process. While both are needed, a product-orientation tends to emphasize the accumulation of facts and terminology. A process-orientation tends to emphasize inquiry and thinking skills. The KSES ask science teachers to place less emphasis on "knowing only scientific facts and information" and more emphasis on "understanding scientific concepts and developing abilities of inquiry" (KSBE, 2001, p. 6). This does not mean knowledge of facts are not important, it simply acknowledges that science instruction must move beyond this as an emphasis. The standards advocate that facts and knowledge be learned in the context of inquiry. In teaching science in this manner, teachers will not be able to cover as many science topics. That is why the KSES advocate, "…studying a few fundamental science concepts (KSBE, 2001, p. 6).

The "Life Long Learning/Life Skills" category relates science to students' every day decision-making. "Extending Mental Abilities" as a reason for including science in the curriculum emphasizes the way science helps students develop creativity and critical thinking skills. These are elements that are consistent with an inquiry (process) approach to science teaching. "Understanding the Natural World" as a reason for science in the curriculum emphasizes how science makes the natural world understandable by explaining elements of the world that surround us. "Outside Expectations" involves preparing for state assessments or preparing for college and careers. It is easy to see how these last two categories could produce pressure to emphasize coverage of material and more traditional (product-oriented) science teaching approaches. In regards to "Outside Expectations," the principal is in a position to guard teachers against these pressures, but it is not likely they will if they do not see how this goal needs to be balanced with the other three.

Research Question 2

Do principals perceive a need to improve science education in their schools?

Principals were asked to respond to several questions on the survey instrument by marking a Likert type rating scale. After each question they were given the opportunity to provide additional comments for clarification. Table 3 provides the mean score for those question that were used in this report as well as a break down according to grade level. Following Table 3, each question is listed separately and underlined. Since the scale for each question is slightly different, each Likert type scale that was used and the point values each response category was assigned has been provided for each question. A summary of the principals' additional comments then follows.

Table 3

Means for Questions 2, 4, & 5 on the survey instrument.

Question number	Mean	K-6 Mean	5-9 Mean	9-12 Mean
2	3.20	3.00	3.10	3.67
4	3.45	3.36	4.00	3.20
5	3.27	3.55	2.20	3.67

Survey Question 2: In your opinion, where would you place science as compared to other subjects or disciplines in level of importance?

1) the least important; 2) less important; 3) the same; 4) more important; 5) the most important

While the mean score of the Likert ranking indicates that overall the elementary (3.00) and middle school (3.10) principals surveyed believed science had the same level of importance as other subject areas, two elementary principals added additional comments that were very much contrary to quantitative data. One of these marked "the same" on the survey, but said, "I would place reading, language arts and math ahead of science in the elementary school." The other clarified that it was less important by saying, "I answer less important because this is a K-4 building."

These comments are consistent with Abell (1990) who reports that elementary teachers believe science to be less important than other subjects. Another elementary principal stated, "Our curriculum is so overloaded. Math, reading, writing, and communication skills are not optional as far as time commitment. I include science most easily and consistently by integrating curriculum." This statement is revealing and provides anecdotal evidence that when pressed for time, some view science as optional at the elementary level. It also provides insights into a strategy that is becoming increasingly popular – integration of subject matter (Esler & Esler, 2001). Howe (2002) discusses how teachers can successfully integrate inquiry-based science with other content areas like reading. However, she warns, "…the problem arises when reading becomes the primary means by which children learn science" (p. 258). For too many, this is the case. Many educators fail to recognize that by providing students time to participate in inquiry based elementary science programs they are actually developing skills in areas they feel as "essential." Esler and Esler (2001) provide a list of additional benefits students receive by doing inquiry type investigations that include such things as serving as a reading readiness program for early primary-grade children, increasing mathematical concepts and increasing language and general knowledge (p.7).

Two comments from elementary principals provide additional insights into some issues regarding science in the elementary classroom. One elementary principal said, "the importance of science is not present in K-5 classrooms." Another elementary principal commented, "Science is a subject that we alternate with social studies and work closely with the science committee to ensure we are covering all areas in science that are being tested of our 4th graders on the State Science Assessments." These are an honest, but potentially distressing statements. Allocating sufficient time for inquiry-based lessons is important. Lowery (1997) states that teachers should "plan for a minimum of 150 minutes per week of science instruction in grades 1-3 and 225 minutes in grades 4-6" (p.138). This translates to approximately 30 minutes per day for grades 1-3 and 45 minutes per day for grades 4-6. If principals do not regard the value of science in the elementary curriculum as highly as other disciplines, they are not as likely to encourage teachers to make the needed time commitment to science. In addition, the comments bring attention to the role state assessments are having in shaping the curriculum.

The mean scores (3.67) of the high school principals indicated that they ranked science as being slightly more important than other subject areas. One commented, "It is very difficult to rank subjects. Much depends on the individual student. However, all need to have a basic understanding of science." Another said, "It is an important core class." Although it is speculation, this slightly higher ranking may be due to the fact that many colleges have entrance requirements that include taking a minimum number of science courses.

Survey Question 4: Are you satisfied with the quality of science instruction your students receive?

1) very unsatisfied; 2) unsatisfied; 3) neutral; 4) satisfied; 5) very satisfied

Only the middle school principals' response on this question indicated a solid level of satisfaction (4.00) with the science instruction. However, one middle school principal provided evidence that satisfaction doesn't necessarily mean inquiry-based learning is occurring. The principal stated he had a "Knowledgeable dedicated staff…" but still had a "…need for more active student participation." Another middle school principal added complexity to this issue by indicating there might be some difference depending on which segment of the student population was being referred too. "I am very satisfied with our top students. I wish we could eliminate aptly by a few students." This is a perplexing statement. It suggests that the principal is not sure all students should be taking science.

Neither the high school (3.20) or elementary school (3.36) principals' mean score indicated a strong a tendency towards being satisfied, yet they weren't dissatisfied either. As one high school principal indicated, "[it is] mixed. Depends on the teacher." One elementary principal recognized, "Students need more process science instruction, but teachers typically teach facts." Another elementary principal that indicated "satisfaction" with the teachers did comment on some curricular constraints. "It is difficult to find a curriculum that has a balance of discovery, reading material and experimentation. We don't have enough hours in the day for some discovery methods." These comments elicit questions such as, How much is process valued in high school science? How much do those "outside" pressures influence the type of science course that is encouraged?

Survey Question 5: With respect to science achievement, is the performance level of students in your school a concern?

1) definitely not a concern; 2) not a concern; 3) neutral; 4) a slight concern; 5) definitely a concern

While middle school principals' mean scores (2.20) indicated they were not concerned, both elementary (3.55) and high school (3.67) principals' mean scores indicated they had tendencies toward having a slight concern, although this was not strong. One elementary principal plainly indicated that, "Every subject area is a concern." Another principal at the elementary level said, "At our level we do not do district or state assessments in science. We only track grades earned in the area." Conversations with teachers provide anecdotal evidence that the administration and content of the state exams does influence classroom practice. In the spring of 2001, the new science assessments were administered in Kansas. The exam gradually decreases in the number of process items with increasing grade levels.

Recognizing the fact that many high school science courses are electives, a high school principal that responded "slightly concerned" said, "We want to get more students in advanced science classes." Encouraging more students to take higher-level science courses in high school is a legitimate concern. Since most advanced science courses are elective, recruitment of students into these classes often relies on creating interest and relevance." However, another high school principal that indicated a "slight concern" provided insights into the complexity of this situation by pointing out an issue that is at the heart of standards-based reform. The principal commented, "Our college bound students do well when they get in college science, mainly in chemistry. They say it is due largely to our instructor's lecture and note taking requirements. The lower level student has difficulty passing." This quote reflects the tenacity by which traditional approaches maintain their integrity in the classroom. This is strengthened when the traditional approach seems to accomplish successfully one purpose for having science in the curriculum. Traditional approaches predominate institutes of higher education, thus those who prepare students in the years prior to college are well aware of the expectations of the college classes. This outside expectation acts to maintain the status quo of traditional teaching. So, how much is process valued in high school science? How much do those "outside" pressures influence the type of science course that is encouraged?

The KSES made it clear that the science standards were "…for all students" (KSBE, 2001, p. 2). These standards ask educators to change the emphasis of science instruction so students develop understanding of the content and the skills of inquiry (KSBE, 2001, p. 27). Texley & Wild (1997) argue that to move in this direction, "teachers, principals, parents, and community members will have to agree that college entrance should no longer be the most important measure of success" (p. 8).

Research Question 3

What are principal's perceptions concerning the critical issues involved in teacher quality identified by the Glenn Commission for each stakeholder group?

For this section of the survey, principals were asked to respond to multiple statements under each of five categories: school district, school building, science teacher, parents of students, higher education. These represented five of the seven stakeholder groups identified by the Glenn Commission as affecting teacher quality. The Likert scale of 1-5 with 1 representing strongly disagree and 5 representing strongly agree. (See Appendix B for the complete set of data). The following sections represent trends from the quantitative data. The categories mentioned above will not be discussed separately as listed. Rather, the discussion has been organized around general trends in the data.

Teacher Initiative

Fullan & Hargreaves (1996) argue that "…the single most distinguishing characteristic of the best professionals in any field is that they consistently strive for results, and are always learning to become more effective, form whatever source they can find" (p. 82). Improvement in science will not happen without the teacher. Principals were asked their level of agreement to whether teachers in their school actively sought new knowledge in their discipline, worked to improve their science teaching skills, and took advantage of the professional development opportunities to improve science teaching. The mean score (3.50) of the principals indicated a slight inclination toward agreement. The mean score for elementary principals was even lower (3.36).

A Culture for Teacher Learning

While Fullan & Hargreaves (1996) acknowledged the individual teacher's responsibility for improvement, they also recognized their need for support. They underscored this conclusion by stating, "But where leadership and school environments are particularly and persistently unsupportive, the success of teacher efforts will be slim, short-lived or non-existent, and teachers will quickly learn not to make them" (Fullan & Hargreaves, 1996, p. 84). This implies that successful reform in science education has to do more than focus on the teachers, it needs to include changes within the schools' work environment. Some have stated that these changes need to produce a culture that promotes teacher learning (Hord, 1997; Sparks, 1999).

Principals were asked to indicate their level of agreement as to whether their building provided teachers who teach science with significant professional development opportunities. Although Likert averages were weaker at the elementary level (3.55), the middle school (3.80) and high school (4.00) principals' averages indicated they tended to agree. A solid level of agreement was also present as to whether their building provides teachers with access to an ever-expanding knowledge base about science teaching. Elementary principals' (3.82) and middle school principals' (3.80) averages were very similar, while high school principals' (4.20) average indicated the highest level of agreement. Results to this same question, but focused on the district instead of the school building were slightly lower and followed the same trend. Elementary (3.55) and middle school (3.60) principals' averages were similar, but showed a more moderate level of agreement, while high school principals' (4.17) average was the highest and indicated a solid level of agreement.

If level of agreement is an accurate indicator of what is actually taking place, it is a positive sign for the science teachers in the schools that were a part of this study. But there is good reason to be skeptical. Rhoton (2001) states that too much of professional development available to science teachers consists of short after-school meetings and stand-alone workshops that are not connected to the realities of the classroom. These forms of professional development have their place, but the problem is they do not deepen teachers understanding of academic content or pedagogical principles. In short, the issue of deep understanding of content is as viable a concern for teachers learning to teach science as it is for students in the science classroom.

In order to promote teacher learning, one has to take into account their need of time for purposeful interaction and collaboration among fellow teachers. Fullan (2001) reported that "…within the school, collegiality among teachers, as measured by frequency of communication, mutual support, help, and so forth, was a strong predictor of implementation success" (p. 124). This implies that as teachers work toward incorporating science standards into their daily instructional routine, they need more than access to information. They also need to interact with each other and provide each other with technical help. This is especially true with new teachers. Principals were asked to indicate their level of agreement as to whether teachers actively share their knowledge and experience with new teachers to help them improve their science teaching. The Likert average for all principals (3.41) wasn't a strong indication of agreement.

Reasons for principals' lack of showing a solid level of agreement relating to teacher sharing are not clear from this study. But there is evidence that part of the cause could be linked to the lack of purposely-planned programs designed to facilitate this type of interaction. Principals were asked their level of agreement as to whether the district had committed funding to ensure that all science teachers had ongoing collaborative opportunities to improve their skills and knowledge of science. Elementary principals' average (3.09) indicated a neutral response. Both the middle school (3.60) and high school (3.67) principals' averages indicated only a slight tendency to agree. Principals were also asked to state their level of agreement as to whether their district actively worked at developing teacher leaders that could facilitate the continuous learning of their colleagues in the area of science. This time, their overall average of (2.82) was even lower.

A Teacher Preparation Continuum

Some argue that teacher preparation should be seen as a continuum that begins during pre-service preparation and extends throughout the career of a teacher (Darling-Hammond, 1996). This means making sure teacher quality starts in the institutions that prepare teachers and continues on with the school buildings and districts that hire them. Once in a school system, new teachers begin an "apprentice" stage that extends into the second or third year of teaching (Steffy, et al., 2000). Steffy et al. (2000) describes teachers in this stage as being idealistic. This is a time when they are open to new ideas. They want to learn more and are willing to try new strategies. At times they feel self-doubt and are unsure of their skills, but they believe "…they have the skills to assure all children will achieve at high levels" (p. 6-7). Unfortunately, about one third of all newly hired teacher leave within the first few years (Darling-Hammond, 1996).

Brock & Grady, (2000) discussed the problems beginning teachers face. Some teachers and principals view beginning teacher struggles as a "rite of passage" or "trial by fire." Even when they see them struggle, they maintain an attitude that says if they "…cannot survive, perhaps they are not strong enough to become teachers" (p. 21). When asked whether their building ensured new teachers had reasonable teaching loads, only the elementary principals' average (4.18) indicated a solid level of agreement. The high school principals' average (3.60) indicated only a slight tendency toward agreement and the middle school principals' average (3.40) was in the neutral region.

It should be noted that being a "new" teacher doesn't just refer to being a beginning teacher. Experienced, but "new" teachers in a school can face challenges of their own. For example, some school's staffs form such close-knit groups that trying to break into these existing social structures can be difficult. Like beginning teachers, they too could benefit from additional mentoring and support. However, none of the principals' averages (3.14) relating to whether their building ensured mentoring and other support for new teachers indicated agreement. The principals' overall Likert average (3.00) also indicated they didn't agree that the district provided a formal induction program and induction policies either.

Brock & Grady (2000) reported that many principals recognize that beginning teachers need help, but "…struggle with the mechanics of providing that help" (p.48). They reported the results of a study by Cole (1993) that found principals would like to know more about beginning teacher needs, attend professional development related to induction, and discuss issues related to induction with other administrators. These conclusions are consistent with the responses of principals in this study. When asked if it would be helpful for their school to work closely with an institution of higher education to assist in identifying existing and future needs for developing highly qualified K-12 science teachers, the overall principals' average (3.95) indicated they had a solid level of agreement. Their overall average (3.91) also indicated they agreed that it would be helpful for their school to collaborate with an institution of higher education to ensure a quality induction process for new science teachers.

Kansas statutes prevent school districts from hiring "unqualified" teachers. However, a school district can apply for a waiver to allow a teacher that does not hold the proper endorsement for his or her assignment to teach. In 1999-2000, there were 189 waivers approved by the Kansas State Board of Education (KCTAF, 2000). It is probable that these individuals will need the same level of consideration as new teachers. Principals were asked to provide their level of agreement as to whether their building ensured that a mentor or other ongoing support was available to teachers that were assigned to fill a science position, but lacked the necessary qualifications. None of the principals' averages indicated agreement (3.14).

Martin (2000) reports that The National Science Teachers Association affirms "…parents play an essential role in the success of students in school" (p. 325). While this refers to the impact parental influence and support can have on students' mastery of science concepts and skills, it could also apply to the impact parental influence and support can have on the success of a school. As taxpayers, members of parent groups, and voting members of the community, their opinions in rural school matters are important. Principals were asked their level of agreement as to whether parents would support efforts to provide teachers with opportunities to improve their teaching skills. Likert averages from all the principals indicated they agree (3.90). Agreement was especially strong at the elementary level (4.09). Interestingly enough, when asked if parent would support increased funding for programs that support quality science teaching, the overall Likert average (3.00) for all principals drops off considerably. In sum, their perception is that parents will support efforts to improve science instruction, but not with money.

Conclusions

Because this was a pilot study, any conclusions are tenuous at best and generalizability is limited. However, the data does raise questions that call for further investigation. First, in spite of the urgency in reports like Before It's Too Late , principals in this study did not seem to demonstrate the same level of urgency about needing to address reform in science education. None of the principals' averages in any category was at a level of strongly agree. Many of their averages fell into the neutral category. Interpreting what "neutral" meant for these principals was difficult and illustrates a limitation of this study. Although unlikely, one interpretation could be that principals felt they lacked enough knowledge to indicate any level of agreement or disagreement. Another more probable explanation is that they did not feel a strong desire to commit to either side of the scale. They truly were in a neutral state between agreeing and not agreeing.

From comments, it is clear that some elementary principals feel the pressure of an over loaded curriculum that brings with it conflicting needs. While some seemed to understand the importance of inquiry based teaching in science and provided reasons for including it in the curriculum that are consistent with standards based science reform, they also indicated other subject areas like mathematics and reading take priority. This all or none approach is discouraging for science education reform at the elementary level. A solution some have found helpful is to integrate subject matter. While this solution does have promise, it is important that science not lose its' integrity of content or process.

At the secondary level, principals have a separate set of issues. Most agree that science is an important part of the curriculum. Comments suggest that some even recognize the need to recruit students into higher-level science courses. However, there is evidence that for some, higher-level science courses are a means for college preparation. While this is valid reason, it neglects the needs of many other students. The tendency to view science instruction from this stance disenfranchises students from entering science classes and subsequently science related fields.

Another potential concern deals with teacher learning opportunities. Many principals indicated that access to knowledge and professional development was available. However, the evidence doesn't suggest that financial support, time, or resources are being made available for mentoring, induction programs, and collaborative opportunities. Without these types of opportunities and support, teacher learning will be severely limited.

There does seem to be an area that holds promise to assist in science teacher development. Many principals in this study recognize and are open to ideas for help in developing induction programs and assisting with teacher needs. Unfortunately for many rural schools, geographical isolation is an added issue that must be overcome.

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Appendix A

Data Tables from the Survey

Table 1

Years of experience as a principal

n=21

Years of Experience	0-1 years	2-4 years	5-10 years	10 + years
# of principals	2	9	6	4

Table 2

Summary for Likert Question 2-5 on survey instrument.

#	Average	K-6 Average	5-9 Average	9-12 Average
2	3.20	3.00	3.10	3.67
3	2.95	3.10	3.00	2.67
4	3.45	3.36	4.00	3.20
5	3.27	3.55	2.20	3.67

Table 3

Stakeholder Group Data: the school district

School District Level	**Average**	**K-6**	**5-9**	**9-12**
Our district has a common vision for promoting a high level of student achievement in science.	3.68	3.73	3.40	3.83
Our district uses accurate data to develop policies that will improve science teaching.	3.18	2.83	3.60	3.67
Our district has committed funding to ensure that all science teachers (who will teach science) have ongoing collaborative opportunities to improve their skills and knowledge in science.	3.36	3.09	3.60	3.67
Our district only hires teachers (who will teach science) that have the necessary qualifications. *(ex: only people certified in life science teach life science)*	3.59	3.00	4.00	4.33
Our district aggressively recruits high quality teachers to teach science *(e.g., by offering signing bonuses or giving salary credit for all previous experience).*	2.82	2.55	3.00	3.17
With respect to teaching science, our district provides competitive salaries to attract and retain the best-qualified science candidates.	3.09	2.91	2.80	3.67
Our district ensures that new teachers (who will teach science) receive the support necessary to be effective by providing a formal induction program and instituting induction policies. *(e.g. by limiting extracurricular duties, ensuring, frequent interaction with master teachers, etc..)*	3.00	2.91	3.20	3.00
Our district actively works at developing teacher leaders that can facilitate the continuous learning of their colleagues in the area of science.	2.82	2.82	2.80	2.83
Our district provides teachers access (including electronic) to an ever-expanding knowledge base about science teaching.	3.73	3.55	3.60	4.17

Table 4

Stakeholder Group Data: the school building

School Building Level	**Average**	**K-6**	**5-9**	**9-12**
My building provides those teachers who teach science with significant professional development opportunities to improve their teaching.	3.71	3.55	3.80	4.00
Our building provides teachers access (including electronic) to an ever- expanding knowledge base about science teaching.	3.90	3.82	3.80	4.20
My building ensures that new teachers (who will teach science) have frequent interaction with mentor teachers that can assist them in this subject area.	3.14	3.27	3.20	2.80
My building ensures that new teachers (who will teach science) have reasonable teaching loads.	3.86	4.18	3.40	3.60
If there are no other options, but to assign a teacher that lacks the necessary qualifications to teach a science class *(ex. using a biology person to teach physics or a generalist to teach a specialist course like life science.)* my building makes sure a mentor and other ongoing support is available.	3.14	3.27	3.00	3.00
My building ensures that opportunities to pursue careers in science teaching are emphasized for students in the school (ex: job shadowing, career fairs, etc…).	3.57	3.18	4.00	4.00

Table 5

Stakeholder Group Data: the science teachers

Science Teachers	**Average**	**K-6**	**5-9**	**9-12**
Our teachers (that teach science) actively seek new knowledge about teaching in their discipline, work on a continuous basis to improve their science teaching skills, and take advantage of the professional development opportunities to improve their science teaching.	3.50	3.36	3.60	3.67
Our teachers (that teach science) work to improve their knowledge and skills to incorporate educational technology into their learning and teaching of science.	3.59	3.18	4.00	4.00
Our science teachers utilize well-defined science standards to determine what knowledge and skills children are expected to obtain at various grade levels.	3.86	3.73	4.20	3.83
Our teachers regularly assess the achievement levels of their students against these science standards to identify areas for improvement, set goals, and make plans for achieving these goals.	3.50	3.27	3.80	3.67
Our science teachers communicate to parents the specific standards that students are to meet at each grade level and update them on their child's progress in meeting these standards.	2.86	2.73	3.20	2.83
Our teachers (that teach science) actively share their knowledge and experience with new teachers to help them improve their science instruction.	3.41	3.27	3.60	3.50

Table 6

Stakeholder Group Data: Parents

Parents of Students	**Average**	**K-6**	**5-9**	**9-12**
Parents in our district know about the science standards that their children are expected to meet.	2.82	2.64	2.80	3.17
Parents in our district have a clear picture of how well our school is doing in meeting these standards.	2.82	2.73	2.80	3.00
Parents in our district would support the school's efforts to hire well-qualified science teachers.	4.09	4.18	3.60	4.33
Parents in our district would support the school's efforts to provide teachers with opportunities to continually improve their skills in teaching science.	3.90	4.09	3.75	3.67
Parents in our district would support increased funding for programs that support quality science teaching.	3.00	2.91	3.00	3.17

Table 7

Stakeholder Group Data: Higher Education

Higher Education	**Average**	**K-6**	**5-9**	**9-12**
It would be helpful for our school to work closely with an institution of higher education to assist in identifying existing and future needs for developing highly qualified K-12 science teachers.	3.95	3.91	4.00	4.00
It would be helpful to for our school to collaborate with an institution of higher education to ensure a quality induction process for new science teachers is in place.	3.91	3.91	3.80	4.00
Teacher preparation institutions need to improve their pre-service programs to better meet the criteria for exemplary science teacher preparation.	3.73	3.64	3.40	4.17
Teacher preparation institutions should work on recruiting strategies and should provide incentives for eligible students to focus on science in their preparation.	4.00	4.09	3.80	4.00
Teacher preparation institutions need to do a better job of evaluating and tracking their science teacher graduates performance in science teaching after they graduate from their programs.	3.41	3.45	2.80	3.83

TEACHER-STUDENT CO-CONSTRUCTION IN MIDDLE SCHOOL LIFE SCIENCE

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In recent years there has been an increasing recognition of scientific reasoning as a social process that involves conjecture and argumentation (Newton, Driver, & Osborne, 1999). This recognition implies that scientific ideas may not be readily discovered by the students through empirical processes alone. Rather, learning science "involves being initiated into the ideas and practices of the scientific community and making these ideas and practices meaningful at an individual level" (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 6). The teacher plays a key role in this initiation process by providing experiences and helping the students to build understanding of scientific conventions. These activities may take the form of a dialogue or conversation through which the teacher and the students exchange ideas to produce conceptual change. In other words, the teacher becomes a partner who guides students in a process that we call co-construction of knowledge (Rea-Ramirez, 1998). This co-construction can also be seen as a process of shared reasoning (Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993).

In the recent literature there are many articles in which researchers examine the process through which the students build understanding about a topic together. It is possible to find a diverse array of contents, contexts, models, and research traditions. For instance, some discuss the most appropriate number of students for optimal discussion in a small group (Alexopoulou & Driver, 1996). Others examine the process of argumentation while the students are dealing with socio-scientific issues (Kuhn, Shaw, & Felton, 1997; Osborne, Erduran, Simon, & Monk, 2001; Resnick et al., 1993). Still others use models such as Toulmin's theory to describe the argumentation processes that are taking place (Driver, Newton, & Osborne, 2000; Jimenez-Alexaindre, Bugallo Rodriguez, & Duschl, 2000; Kelly, Druker, & Chen, 1998; Osborne et al., 2001; Pontecorvo & Girardet, 1993; Toulmin, Rieke, & Janik, 1979; Toulmin, 1958). However, these articles do not focus on teacher-student interactions. Bruner's scaffolding metaphor (Fleer, 1992); theoretical models that combine the ideas of Piaget, Vygotsky, Bakhtin, and Wertsch (Mortimer & Machado, 2000); and Davidson's philosophy (Klaassen & Lijnse, 1996) put forth still other theories for describing teacher and students exchanges. Research traditions such as ethnography (Crawford, Kelly, & Brown, 2000) have been used to explore issues of values, power, and authority (Smith & Anderson, 1999; Tobin, McRobbie, & Anderson, 1997) in describing teacher-student conversations. Other articles explore the process of argumentation while students present data (Frazier, 2001), conduct practical scientific inquiries (Watson, Swain, & McRobbie, 2001), and work with computers (Kelly & Crawford, 1996).

Finally, other researchers have taken a more cognitive approach by generating patterns and mechanisms to explain teacher/student or student/student argumentation processes (Anderson, Chinn, Chang, Waggoner, & Yi, 1997; Bloom, 2001; Duit, Roth, Kmorek, & Wilbers, 1998; Hogan, Nastasi, & Pressley, 2000; Inagaki, Morita, & Hatano, 1999; Leander & Brown, 1999; Resnick et al., 1993; Schwarz, Neuman, & Biezuner, 2000; van Zee & Minstrell, 1997a; van Zee & Minstrell, 1997b). Even though their approaches for describing the argumentation process are quite valuable, none of the articles explained the cognitive processes of the teacher and the students working together while building mental models of a topic.

A Different Approach to Model Construction

In contrast, there have been a number of recent publications related to models and modeling in science education (Buckley, 2000; Clement, 2000b; Gobert, 2000; Gobert &

Buckley, 2000; Harrison, 2000; Justi & Gilbert, 2000; Rea-Ramirez, 1999; Snyder, 2000; Steinberg & Clement, 1997; Steinberg & Clement, 2001). These authors propose that both experts and students learn by building and revising models (Clement, 1989; Clement, 1993). In model construction theory the learning process is not a product of a sudden insight within the students' minds but rather the result of small cognitive cycles of model construction and criticism (Clement, 1989; Clement, 1993; Clement, 2000b; Rea-Ramirez, 1998; Steinberg & Clement, 1997; Steinberg & Clement, 2001). These small cognitive cycles are present when the teacher and the students, acting as partners, participate in the co-construction of progressive intermediate mental models.

We mean by co-construction the process through which both the teacher and the students contribute ideas regarding a topic during a discussion or a conversation. During the process, the teacher and the students also acting as partners provide arguments for and against different models to evaluate them.

In this paragraph we will summarize the major instructional model derived from the case study as a preview of the findings. Cognitive dissonance (Clement & Rea-Ramirez, 1997) may be a driving force of the process that originates the small cognitive cycles of model construction and criticism. When the teacher detects a concept that is not in agreement with the current scientific conception in the students' ideas, he/she introduces an event to promote a dissonance. When the students are ready, the event is carefully introduced to produce dissonance big enough to avoid the students reject or be discouraged by the new idea. The students appear to evaluate and modify their initial preconception in the light of the new notion presented by the teacher. If the students go in the expected direction, the teacher stops presenting dissonance. If the students do not go in the expected direction, the teacher presents a new event to promote a new dissonance and so on. By fostering these small cognitive cycles of model construction and criticism, the teacher helps the students to slowly repair the incorrect ideas and fill in the "gaps" present in their mental models. The repetition of this process over and over again leads to the emergence of progressive intermediate mental models in the students' understanding about a concept.

Purpose of Study

The purpose of this study is to begin to explain the co-construction processes of the teacher and the students working together while building mental models. The questions that guided the study were: Is there any evidence of student model construction? What teaching tactics are promoting mental model construction? Is there a general way to describe the teacher's actions and the students' learning processes?

A micro analysis was conducted to provide a case study of the co-construction process occurring in one of the units taught. The findings presented in this paper are organized around three nested processes. The outer process is called Macro Cycle, the middle process Micro Cycle, and the inner process Teaching Tactics. In other words, Micro Cycles were a subprocess used within a Macro Cycle, and Teaching Tactics were subprocesses used within Micro Cycles. Through the description of these nested processes of interaction, this paper intends to develop an explanatory model of the both teacher's and students' cognition.

Unit of Instruction Studied

This study is an analysis of small group tutoring sessions on human respiration. Four two-hour classes were held with a group of four eighth-grade students. The group included two boys (G and L) and two girls (B and Mi) and was ethnically diverse. The teacher (M) was a researcher in the project. Each session was audio- and videotaped.

Rea-Ramirez (1998) developed the instructional sequence as a pilot study of a curriculum based on model construction and criticism theory. The instruction was organized around five target models as the content goals of instruction each related to a unit connected to respiration. The units were the cellular makeup of the body, the internal structure of the cell, and the digestive, the circulatory, and the respiratory systems.

This paper is focussed primarily on the circulation unit. At that point in the sequence, the students have observed cells under the microscope with high magnification, and know about the internal structure of the cell. For instance, they learned that cells contain a nucleus, endoplasmic reticulum and mitochondria. Students also learned that the mitochondrion is the place where glucose and oxygen are combined to get energy, carbon dioxide, and water. In the circulation unit, the students and the teacher discussed how the cells get glucose and oxygen and simultaneously get rid of the carbon dioxide.

During the instruction for each individual target model, the teacher first asked the students to draw their initial ideas about the target. Students discussed their models among themselves and with the teacher. The teacher encouraged them to question and revise their own and other students' models. During the instruction, the teacher coordinated several teaching tactics such as analogies, hands-on activities, computer animations, discussion, and drawings to promote further model construction and revision. At the end of this process, students were presented with a computer animation that contained the scientific conception of the target model. Finally, the students were asked to go back to their initial drawings and revise them.

Methods

The data used in this study were obtained from transcripts, observations, pre- and post-instruction interviews, and students' drawings. Quantitative and qualitative data analyses were conducted. In the quantitative analysis pre- and post-instruction interviews were coded and a paired mean comparison (t-test) was conducted to determine the effect of the instruction on the students' understanding of human respiration.

In the qualitative analysis, a generative analysis was conducted to develop an explanatory model of the co-construction process. In a generative analysis, "analysts construct, criticize and revise hypothesized models of mental structures and processes repeatedly while using them to explain as much of the data in a protocol or a set of protocols as possible" (Clement, 2000a, p. 555-556). An explanatory model is a hypothesized mechanism to explain the data obtained from the protocols.

From the qualitative analysis, three nested processes emerged. The outer process is called the "Macro Cycle" and describes both the teacher's strategies and the students' learning processes in the large conceptual units of instruction or target models. The middle processes are called Micro Cycles and describe the cognitive mechanisms involved in the co-construction and revision of segments of a mental model. The inner process describes the teaching tactics and its coordination done by the teacher within the Micro Cycles. Progressive intermediate mental models of a "learning pathway" were also identified. In a learning pathway the intermediate models (M_1, M_2, and M_{n+1}) are generated until they reach the target (Clement, 2000b).

Results

We gathered evidence suggesting that students greatly increased their comprehension of human respiration. Quantitative analysis showed that the small group had an overall significant mean difference ($p<.005$) of over three standard deviations between the pre and post scores. Examination of drawings also showed a progression from naïve and incomplete models to detailed models much closer to the scientific view. In addition, over the course of the instruction the students reached high levels of interaction among themselves and with the instructor.

We will attempt to explain the observed gains by unpacking the use of the Macro Cycles, Micro Cycles, and teaching tactics that were described above. This paper, however, will focus primarily upon the Micro Cycles, where co-construction is situated.

Macro Cycles

The Macro Cycle is our hypothesis about the presence of a large pattern within each unit of instruction (See Figure 1.) The circular diagram shows an external and internal pattern. The outer circumference corresponds to the Macro Teacher Cycle. It contains several steps that were inferred from the teacher's behaviors. The inner circumference corresponds to the Macro Student Cycle and depicts the students' cognitive processes inferred while building models. The Macro Cycle developed for each individual target model lasted between 45 minutes and 1.5 hours.

The Macro Teacher Cycle contains several phases: *Introducing the Topic, Detecting Student Ideas, Building on Student Ideas, Comparing the Student and the Scientific Models, and Adjusting the Student Model.* In parallel with these, the Macro Student Cycle appeared to have had the following phases: *Retrieving Schemata, Generating and Initial Mental Model (M_1), Building a New Mental Model (M_2), Comparing the Student and the Scientist Models (M_3), and Comparing Final and Initial Models (M_3 & M_1)* to reach the target model. (See Figure 1.) A linear diagram of a Macro Cycle is also included. (See Figure 2.)

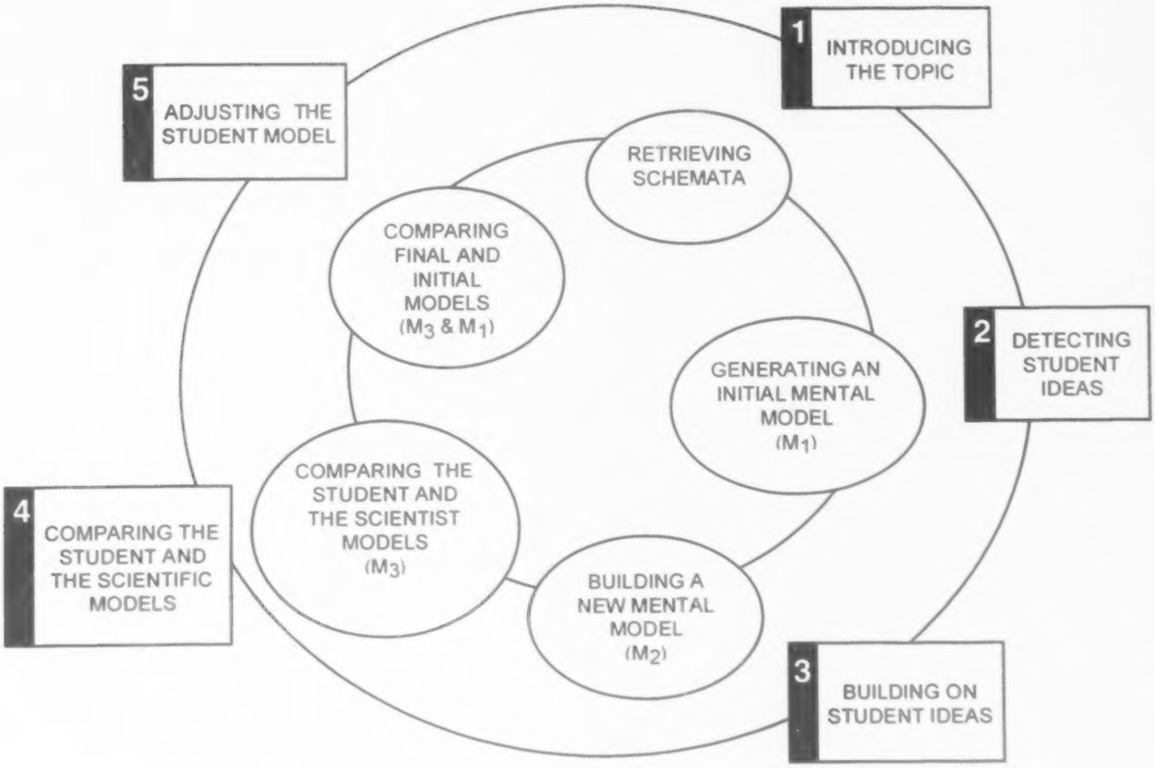
1 INTRODUCING THE TOPIC
2 DETECTING STUDENT IDEAS
3 BUILDING ON STUDENT IDEAS
4 COMPARING THE STUDENT AND THE SCIENTIFIC MODELS
5 ADJUSTING THE STUDENT MODEL
RETRIEVING SCHEMATA
GENERATING AN INITIAL MENTAL MODEL (M1)
BUILDING A NEW MENTAL MODEL (M2)
COMPARING THE STUDENT AND THE SCIENTIST MODELS (M3)
COMPARING FINAL AND INITIAL MODELS (M3 & M1)

Figure 1. Circular Diagram of the Macro Teacher and Student Cycles

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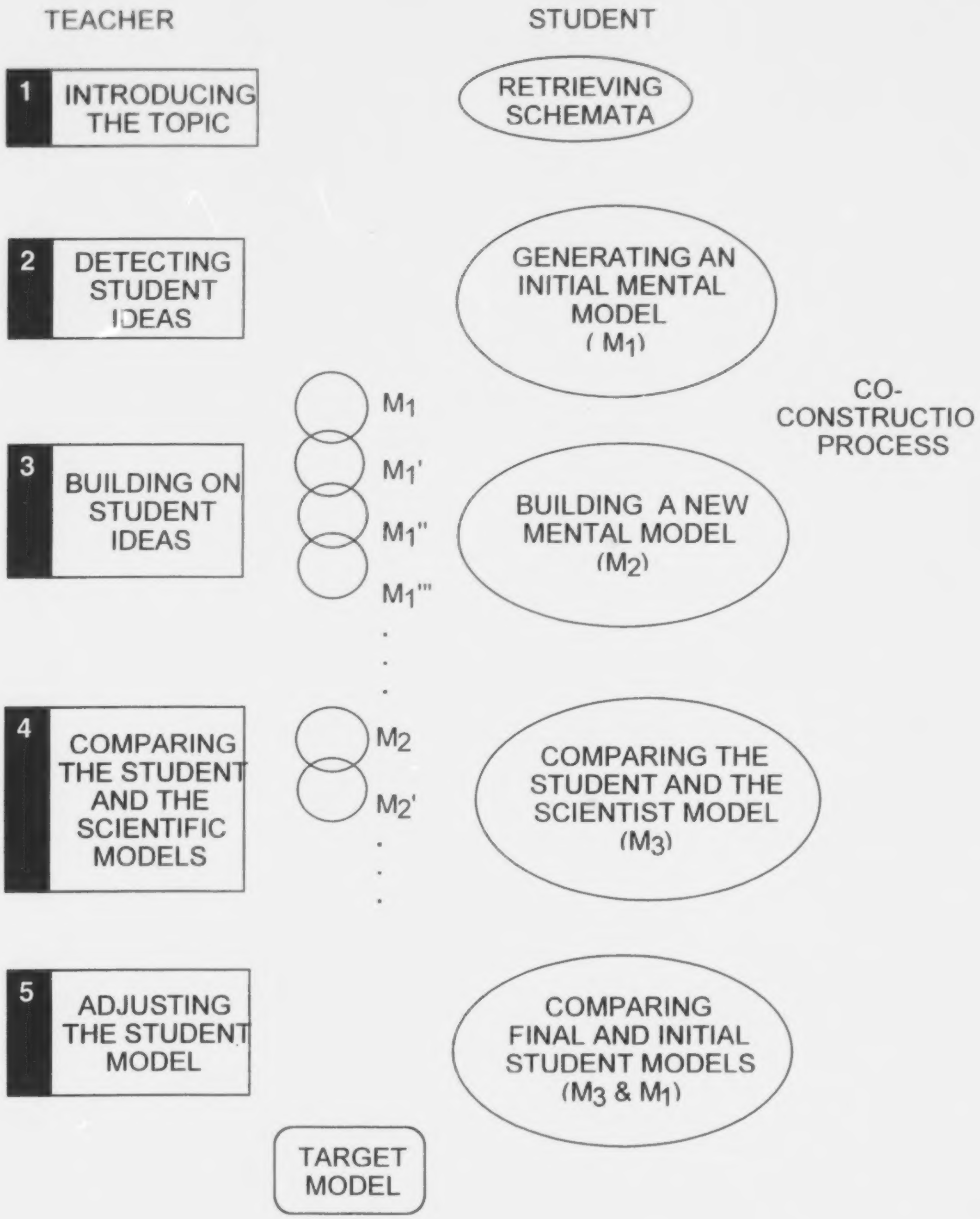

TEACHER
STUDENT
1
INTRODUCING THE TOPIC
RETRIEVING SCHEMATA
2
DETECTING STUDENT IDEAS
GENERATING AN INITIAL MENTAL MODEL (M1)
M1
M1'
M1''
M1'''
CO-CONSTRUCTIO PROCESS
3
BUILDING ON STUDENT IDEAS
BUILDING A NEW MENTAL MODEL (M2)
M2
M2'
4
COMPARING THE STUDENT AND THE SCIENTIFIC MODELS
COMPARING THE STUDENT AND THE SCIENTIST MODEL (M3)
5
ADJUSTING THE STUDENT MODEL
COMPARING FINAL AND INITIAL STUDENT MODELS (M3 & M1)
TARGET MODEL

Figure 2. Linear Diagram of the Macro Teacher and Student Cycles

In the following paragraphs, a description of the steps of the Macro Cycle will be provided. The information will act as an advanced organizer.

Phases of the Teacher and Student Macro Cycle

In the *Introducing the Topic* phase, the teacher reminded the students of previously learned information and presented them with the new target model. At the same time, the students retrieved their schemata of the content.

In the *Detecting Student Ideas* phase, the teacher asked the students to build an initial model (M_1) about the target. The teacher asked the students an "explanation question" that was answered by the students through drawing and describing their ideas aloud.

In the *Building on Student Ideas* phase, the teacher guided the students' thinking to build a more sophisticated model (M_2) of the target. To do that, the teacher and the students worked as partners to build intermediate mental models through several small cognitive cycles of model construction and criticism. Rea-Ramirez (1998) called the partnership "teacher/student co-construction."

Within the co-construction process, the teacher promoted in the students "small cognitive cycles of model construction and criticism" or Micro Cycles. These Micro Cycles are depicted as small circles and they are nested inside the Macro Cycles. (See Figure 2.) Within the Micro Cycles, the teacher coordinated several kinds of teaching tactics. Micro Cycles and teaching tactics will be discussed in more detail later.

In the *Comparison of the Student and the Scientific Models* phase, the teacher encouraged the students to develop a more sophisticated mental model (M_3) of the target than the previous one. To do that, the teacher presented the students with a computer animation, which contained the scientific model. It is important to note that the scientific model is not presented as the final 'correct' model but as a scientist's or artist's interpretation of the concept. In this way students were encouraged to criticize this model as well as their own. When students assessed and compared their drawn models with the scientific model, they often found a piece that they were missing or found clarifying information, especially in animation form, that helped the student put together their final model. This, then, does not leave the student with the idea that they have just worked hard to construct a model that is now 'put aside' for the 'correct' model but rather have been given further evidence and support in the construction process.

In the *Adjusting the Student Model* phase, the teacher encouraged the students to see their own conceptual change at a metacognitive level. To do that, the teacher asked the students to compare their newest model (M_3) with their prior drawings (M_1) and modify M_1 if they thought it was necessary. Finally, the teacher asked the students to apply their new understanding to solve problems and new situations.

It should be noted that students sometimes spontaneously asked questions or suggested personal experiences without direct teacher intervention. In addition, one student contributed analogies to the discussion. For example, he suggested that a red blood cell that brings oxygen to a cell and carries carbon dioxide away from it is like a UPS truck which drops off one package and picks up another.

Teaching Tactics

At this point we will postpone discussion of the middle level of the nested processes, Micro Cycles, in order to describe the innermost level of small teaching tactics. Teaching tactics is our hypothesis about the kind of strategies used by the teacher during the co-construction process. The use of each of these tactics lasted approximately between less than one minute (i.e., questions) to 12-15 minutes (i.e., analogies).

The teacher used two kinds of teaching tactics during the construction of an intermediate mental model, "dissonance and construction producing tactics" and "supporting tactics." "Dissonance and construction producing tactics" were those activities able to produce dissonance or construction or sometimes both in the students' minds (Clement & Rea-Ramirez, 1997). "Supporting tactics" were those activities that allowed the teacher to keep the reasoning process going. In addition, "supporting tactics" provided the teacher with some feedback about the effect of the "dissonance and construction producing tactics" were having on the students' models.

Among the "dissonance and construction producing tactics," we include *Analogies, Hands-on Activities, Recalled Life Experiences, Pictures, Small Pieces of Information, Computer Animations,* and *Questions*. Among the "supporting tactics" we include *Explanatory Need, Thinking Aloud, Drawings, Model Stage Summaries, Dialogue*, and *Questions*.

The teacher used questions both as "dissonance and construction producing tactics" and as "supporting tactics." By using questions as "dissonance and construction producing tactics," she introduced new ideas or counter arguments to promote dissatisfaction within the students' models. Among the *Questions* that acted like "dissonance and construction producing tactics" the teacher used "hint questions," "discrepant questions," "recalling-information questions," and "student questions."

By using questions as "supporting tactics," she detected the effect of constraints and the new ideas or counter arguments in the students' models and kept the model construction process going. Among the *Questions* that acted as "supporting tactics" the teacher used "explanation questions," "information-seeking questions," "prediction questions," and "assessment questions."

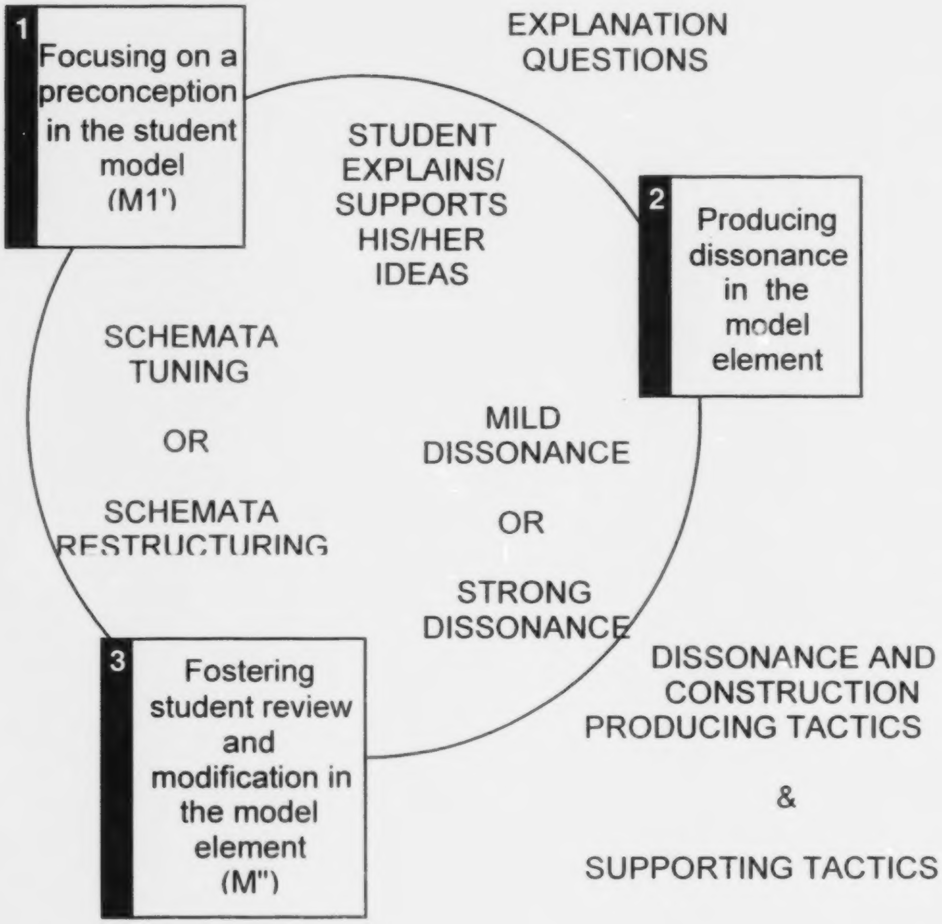
While the "supporting tactics" were used throughout the entire instructional sequence, the "dissonance and construction producing tactics" were only used in the construction and criticism of intermediate mental models. A few tactics such as *Drawings* and *Questions* were used as both "dissonance and construction producing" and "supporting" tactics.

While the teacher guided the students in constructing progressive intermediate mental models, she used several different "dissonance and construction producing tactics" to promote dissatisfaction within the students. The "dissonance and construction producing tactics" (*Analogies, Questions, Recalled Life Experiences, Pictures, Hands-on Activities*, and others) were like a "tool box" to be used by the teacher. Instead of selecting and using a "dissonance and construction producing tactic" at random, the teacher appeared to have chosen the most appropriate tactic to promote dissonance within the students.

Micro Cycles

The Micro Cycle is our hypothesis about the presence of small cognitive cycles or "construction and criticism cycles." These small cognitive cycles were depicted as little circles in Figure 2. They constitute a finer level of cycling occurring within each Macro Cycle. Each individual Micro Cycle lasted approximately five minutes. Their structure is unpacked and expanded in Figure 3. These small cognitive cycles appear to us to be the core mechanism of model construction and criticism theory involved in the co-construction process of knowledge. These Micro Cycles were more evident during the *Building on Student Ideas* phase of the Macro Cycle.

The Micro Cycle describes the way the teacher directs the students' thinking to generate, review, and modify an element inside of their models. (See Figure 3.) The circular diagram shows an external and internal pattern. The outer circumference corresponds to the steps followed by the teacher when she was supporting the students in the process of building small segments of a larger mental model. The inner circumference corresponds to the students' cognitive processes while building small segments of a larger mental model of human respiration. The external diagram was called Micro Teacher Cycles, and the internal diagram was called Micro Student Cycles.



1
Focusing on a preconception in the student model (M1')
EXPLANATION QUESTIONS
STUDENT EXPLAINS/ SUPPORTS HIS/HER IDEAS
2
Producing dissonance in the model element
SCHEMATA TUNING
OR
SCHEMATA RESTRUCTURING
MILD DISSONANCE
OR
STRONG DISSONANCE
3
Fostering student review and modification in the model element (M")
DISSONANCE AND CONSTRUCTION PRODUCING TACTICS
&
SUPPORTING TACTICS

Figure 3.Circular Diagram of the Micro Teacher and Student Cycles

The Micro Teacher Cycle phases and the Micro Student Cycle phases are also closely connected. The Micro Teacher Cycles have the following phases: *Focusing on a Preconception in the Student Model (M_1'), Producing Dissonance in the Model Element,* and *Fostering Student Review and Modification of the Model Element (M_1'').* The Micro Students Cycles have the following phases *Student Explains/Supports His/Her Ideas, Mild or Strong Dissonance*, and *Schemata Tuning or Restructuring.* Through these phases, the students' misconceptions as well as the "gaps" detected by the teacher in the students' initial models (M_1) can be repaired.

In the following paragraphs, our hypotheses about what is occurring within the small cognitive cycles of model construction and criticism will be provided.

Phases of Micro Teacher and Student Cycle

In the first phase of a Micro Teacher Cycle, *Focusing on a Preconception in the Student Model (M_1')*, the teacher focused her attention as well as the students' attention on an incorrect, naïve, incomplete, or missing piece ("gap") in the student's model (M_1'). (All of these will be called a preconception for the reminder of the paper). (See Figure 3.) The teacher also detected the students' supporting ideas in respect to each preconception encountered.

In the second phase of a Micro Teacher Cycle, *Producing Dissonance in the Model Element*, the teacher attempted to introduce dissonance into the students' model. (See Figure 3.) Often, the students appeared to experience mild or strong dissonance. The teacher selected a "dissonance and construction producing tactic" to promote dissatisfaction in their models. The selection of the optimal "dissonance and construction producing tactic" to promote dissonance may have depended on the students' preconceptions about a topic.

When the students had more preconceptions on the topic, the teacher presented them with *Questions* and *Hands-on Activities* that acted like a "discrepant event." When the students seemed to have had fewer preconceptions on a topic, the teacher included an *Analogy* to help the students to build a conceptual anchor for that topic. When the students had so little background that they could not figure out an element of the model by themselves, the teacher provided them with a *Small Piece of Information* to fill in the "gap" in the model. The exposure of "gaps" seemed to foster dissatisfaction in the students' minds.

To introduce the most appropriate "dissonance and construction producing tactic" at the right moment, the teacher appeared to have been very aware of the students' mental models. In addition to the teacher, the students also provided questions, and debated their ideas. Some of them may have also produced dissonance within their classmates and the teacher's minds. Depending on the contradiction level between the students' ideas and the new idea presented by the teacher through the "dissonance and construction producing tactics," the students seemed to have experienced various degrees of dissonance or dissatisfaction. In some Micro Cycles, the students' dissonance seemed to have been mild, while in others the students appeared to have had a much stronger dissonance.

In the third phase of the Micro Teacher Cycle, *Fostering Student Review and Modification in the Model Element* (M_1''), the teacher encouraged the students to review and modify their ideas. (See Figure 3.) To do that, the teacher asked the students an "information-seeking question" such as "what do you think of that" to determine the effect of the "dissonance and construction producing tactics" on the students' model. When the students described their thinking, they seemed to have compared the new idea with their previous model. The comparison may have caused the students to either incorporate the new idea into their thinking, eliminate the new idea from their thinking, or to construct an entirely new cognitive structure to fit the new idea presented by the teacher.

In some Micro Cycles, where the dissonance experienced by the students was mild, they may have engaged in a "schemata tuning" (Rumelhart & Norman, 1978). Schemata tuning is a small adjustment in their old ideas to deal with a counter argument presented by the teacher.

In Micro Cycles where the dissonance experienced by the students was stronger, the student may have engaged in a "schemata restructuring" (Rumelhart & Norman, 1978). A schemata restructuring process builds a new schema for an alternative idea to be included, eliminated or to construct an entirely new cognitive structure.

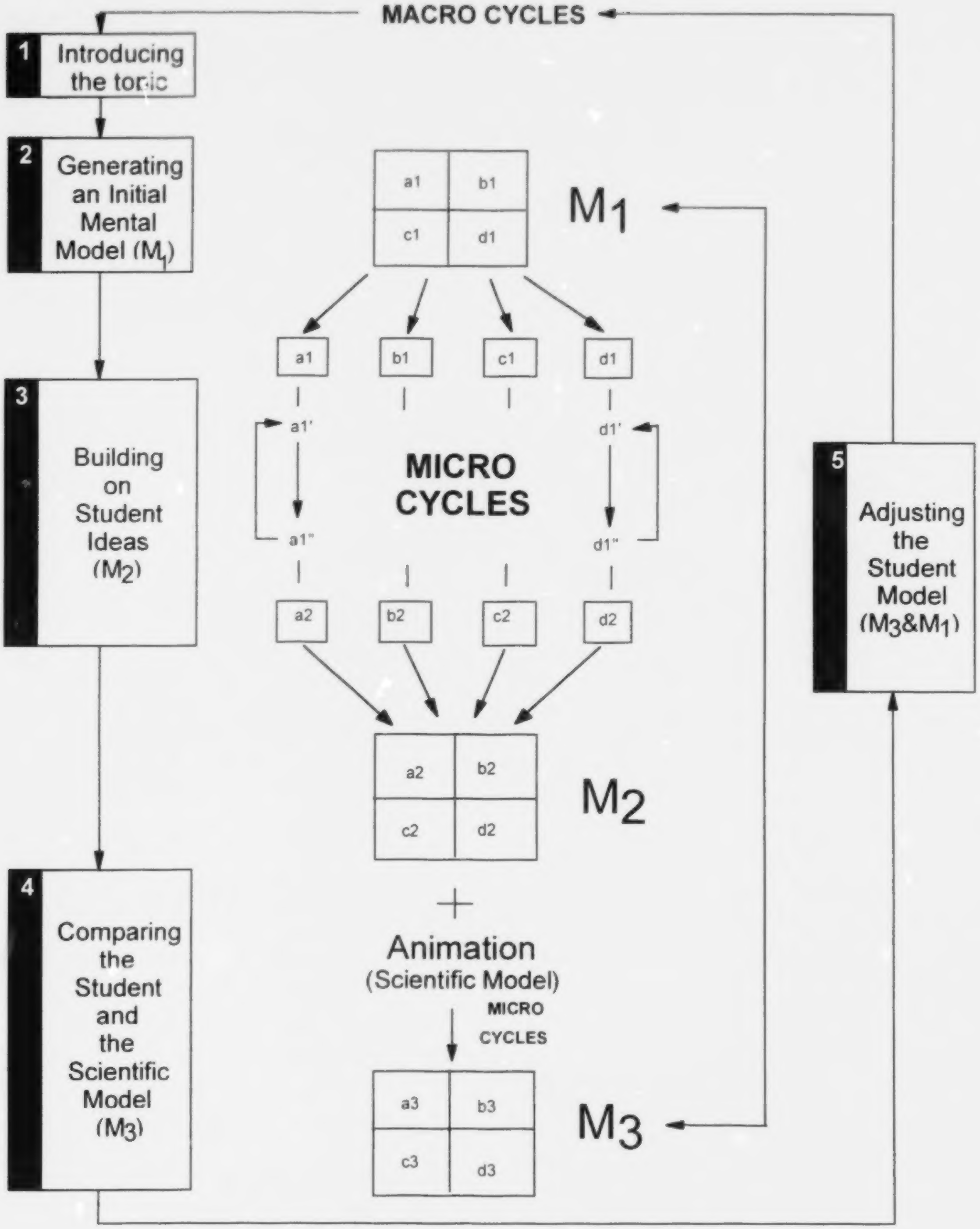
We hypothesize that when the teacher provided the students with *Analogies* or *Small Pieces of Information*, they experienced a mild dissonance ("schemata tuning"). When the teacher provided the students with counter arguments, within a *Question* or a *Hands-on Activity* that acted like a discrepant event, the students experienced a stronger dissonance ("schemata restructuring").

If the students' ideas moved in the desired direction, the teacher appeared to have stopped presenting them with "dissonance and construction producing tactics." If the students' ideas moved in an unexpected direction, the teacher started the entire process again. The Micro Cycles were repeated over and over again until that the teacher helped the students to review and modify the most important preconceptions detected in the initial model (M_1). Throughout this process, the preconceptions detected in the students' primary model (M_1) were slowly repaired to be more in agreement with the scientific point of view. All of the repaired elements appeared to have joined together to create an intermediate model (M_2) of the target.

Throughout the three Micro Cycle's phases, the teacher constantly included "supporting tactics" such as *Thinking Aloud*, *Explanatory Need*, *Dialogue*, *Stage Model Summaries*, *Questions*, and *Teacher/Student Interactions* to keep the process of mental construction and criticism going. We hypothesized that the number of Micro Cycles for each unit of instruction depended on the distance between the students' initial models and the target. In other words, if the students already had some pieces of the target, they would encounter fewer Micro Cycles for each unit.

To help the students to generate a more sophisticated model (M_3) of the target, the teacher presented the students with an *Animation*, which contained the scientific model. While the students were watching the animation, they seemed to have compared their previous model (M_2) with the scientific one. During this comparison the students may also have experienced a few Micro Cycles that lead them to build M_3. However, the dissonance seemed to have been mild because they had already built most of the pieces of the model. At times, the teacher stopped the animation to ask students "explanation questions" that caused them to question and critique the model presented in the animation in light of their own model. In addition, students were asked to make predictions and explain what they were seeing. This encouraged students to be active participants in the animation rather than passive observers. As active participants, students appeared to question both what they were observing and their own models more.

A summary of the entire process is depicted in Figure 4. Letters (a, b, c, and d) represented the individual preconceptions. This process may be useful to teach complex target models other than human respiration.



MACRO CYCLES
1 Introducing the topic
2 Generating an Initial Mental Model (M1)
3 Building on Student Ideas (M2)
4 Comparing the Student and the Scientific Model (M3)
5 Adjusting the Student Model (M3&M1)
M1
a1
b1
c1
d1
a1'
a1"
d1'
d1"
MICRO CYCLES
a2
b2
c2
d2
M2
+
Animation (Scientific Model)
MICRO CYCLES
a3
b3
c3
d3
M3

Figure 4. Summary of the Model Construction and Evolution Process

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Evidence for the Micro Cycles

In the previous section, a description of what can occur within each individual small cognitive cycle of model construction and criticism was provided. The description acted as an advanced organizer. Evidence that supports each of the elements included in that description of the Micro Cycles will be presented in this section of the paper.

In the following paragraphs, five Micro Teacher and Student Cycles included in the co-construction process of the circulatory system will be examined. Figure 5 shows two of these Micro Cycles. In the top row of the diagram, students' utterances are summarized. The bottom row of the diagram shows the teacher's questions. The middle row depicts the "evolving explanatory model." This row contains the sequence of partially correct models that the teacher and the students are building together. The broken lines represent the introduction of dissonance. The straight lines represent the outcome of the thinking that results from the dissonance.

Steps to Leading up to Co-Construction of M_2

Before the Co-construction of a mental model may take place, the teacher has to know the students' preconceptions about the topic. To detect the students' preconceptions of circulation, the teacher asked them an "explanation question." She said, "how do they [glucose and oxygen] get there to those cells in your big toe?" All of the students drew and described an open circulatory system (M_1) with vessels originating from the heart but not returning. Through the *Dialogue* and the *Drawings*, the teacher appeared to have detected an additional misconception the students had. They believed that red blood cells were able to cross the blood vessels walls when nourishing and eliminating waste from the cells of the big toe.

CO-CONSTRUCTION FOR CIRCULATION
(DETAIL)

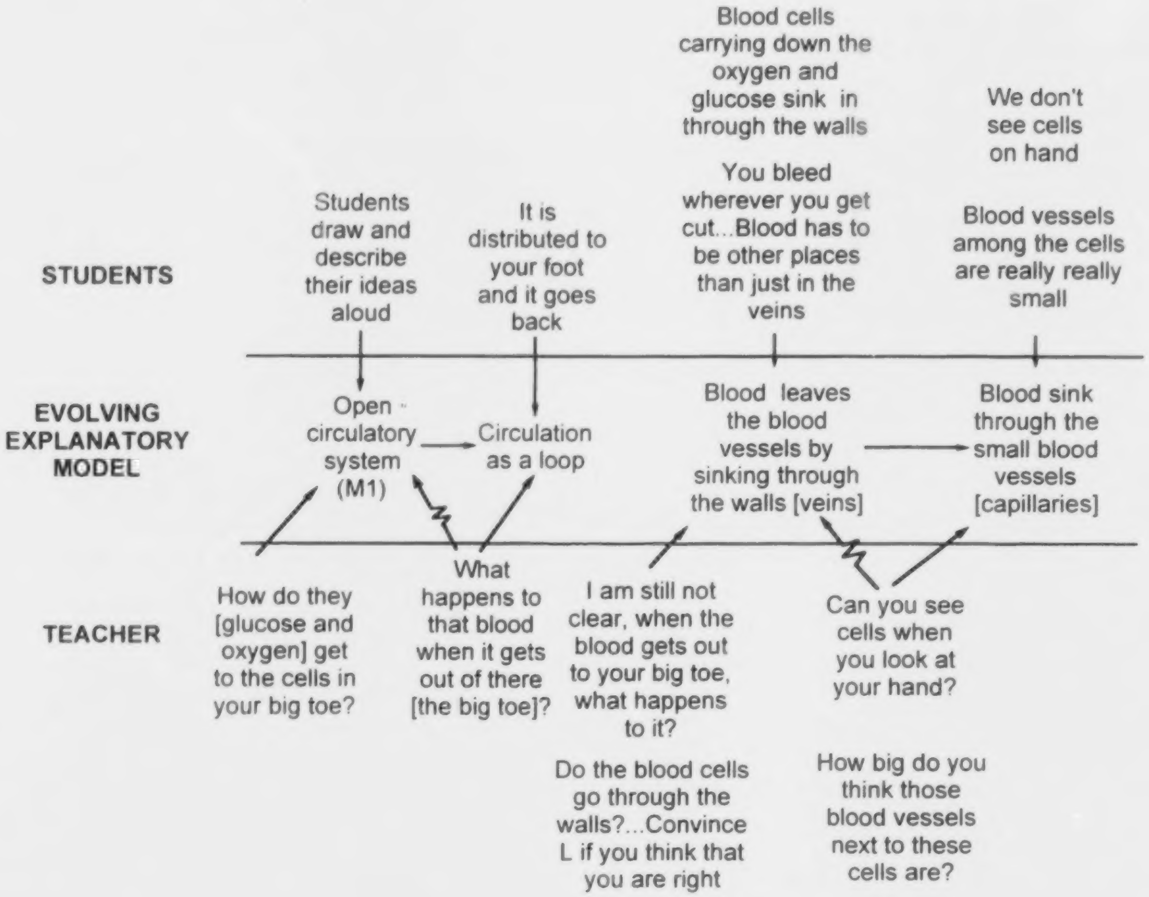
STUDENTS
EVOLVING EXPLANATORY MODEL
TEACHER
Students draw and describe their ideas aloud
It is distributed to your foot and it goes back
Blood cells carrying down the oxygen and glucose sink in through the walls
You bleed wherever you get cut...Blood has to be other places than just in the veins
We don't see cells on hand
Blood vessels among the cells are really really small
Open circulatory system (M1)
Circulation as a loop
Blood leaves the blood vessels by sinking through the walls [veins]
Blood sink through the small blood vessels [capillaries]
How do they [glucose and oxygen] get to the cells in your big toe?
What happens to that blood when it gets out of there [the big toe]?
I am still not clear, when the blood gets out to your big toe, what happens to it?
Do the blood cells go through the walls?...Convince L if you think that you are right
Can you see cells when you look at your hand?
How big do you think those blood vessels next to these cells are?

Figure 5

Co-Construction of M_2

Five Micro Teacher and Students Cycles were developed to promote conceptual change regarding circulation.

First Micro Cycle

The first Micro Cycle started when the teacher directed her attention and the students' attention to a segment of their drawing. In that portion, the students had drawn an incorrect idea from the scientific point of view. The students drew blood vessels only going down to the big toe. However, they did not draw blood vessels coming back up to the heart. The teacher introduced an "explanation question" to closely examine the students' understanding of that element in the model. She asked, "what happens when the blood arrives to the cells of the big toe?" A student said, "blood goes down and then back up." The student' answer was correct from the scientific point of view. However, what she said was not depicted in her drawing. For that reason, the teacher told the students:

> M: So, what does that look like? Can you make sure that's on your drawing?
> Make sure the blood goes down and then back up.

After the teacher asked the students to review and modify their initial drawings, the students changed their ideas *from blood vessels only going down* to *blood vessels going down and then back up to the heart*.

We describe this as the first *Micro Cycle* of the co-construction process of circulation. (See Figure 5.) The teacher detected a preconception in the students' model (blood vessels only going down), then introduced a "hint question" to produce dissonance and construction in the students' thinking while examining their drawings. She said, "something has to happen to the blood at the big toe" and waited for their answer. A student said that blood goes down and then backs up. Based on what the students said, the teacher provided them with another "hint question." She said, "can you make sure that blood goes down and then back up." When the students examined their drawings they may have realized that they did not depict blood vessels going back up to the heart. The recognition of the difference between what they had drawn and what they had said may have produced a mild dissonance in their minds. The dissonance seemed to have promoted the revision and modification of their model ("schemata tuning").

Second Micro Cycle

The second Micro Cycle of the circulatory system began when the teacher focused her attention and the students' attention on another segment of their drawings. In that portion, the students had drawn an incorrect idea from the scientific point of view. The students had drawn lines representing blood vessels going down to the big toe and then going back up to the heart. However, the students did not draw a connection between these lines.

The teacher focused the students' attention on what occurs when blood arrives to the cells of the big toe. The teacher asked them an "explanation question." She said, "OK, OK, so I am still not clear about what happens when blood gets to your toe?" One girl said, "it let's out whatever it's carrying in it." In addition, she added that blood cells are able to "sink in" through the walls of the blood vessels that they called "veins." From her answer, the teacher inferred that when blood arrives to the big toe it comes out of the blood vessels ("veins') to give oxygen and glucose to the cells. The other three students supported her argument and the teacher asked them to provide evidence for their ideas. A boy complemented what the girl said by arguing that blood should be outside of the veins because humans bleed in places where there are no veins:

> L: You bleed wherever you get cut. But you're not always cutting yourself on a vein so obviously blood has to be other places than just in the veins.
> M: Hum.
> L: Because if I cut myself right here [pointing to the back of his hand], there are veins here and here but there's no veins [at the cut] there--you'll still bleed … so that means that the blood has to come out of the vein.

To challenge the students' ideas about blood going out of the blood vessels ("veins") when it arrives to the big toe, the teacher presented the students with a counter argument that seemed to have produced dissonance. She suggested the presence of smaller blood vessels ("capillaries") between the cells by asking the students a "hint question." She said:

> M: Can you see the cells when you look at your hand?
> B: No.
> M: So if I can't see the cells when I just look my hand but I see these blood vessels [Silence] how big do you think the blood vessels [capillaries] are next to those cells? [Silence] I mean if I took a tiny little tiny, even tinier than this pin, right there, [she draws a little dot on the back of her hand] I am looking at a lot of cells, a bunch of cells, OK?
> Mi: Wait, wait is that is that just like glucose…
> M: It's a whole bunch of cells in there. Remember the cells like this [she draws a skin cell cluster on a paper], next to each other?
> B: Uh huh.
> M: How tiny do the blood vessels have to be that are going right between these cells? [She draws a line between the skin cell cluster representing the capillaries located between the cells]
> B: really, really, really, really, really, really small
> M: Oh.
> B: So that's what it does?
> M: So you think I can cut myself and bleed and it will be hard to not hit one?
> Mi: Yeah.
> B: Yeah.

The students acknowledged that in addition to big blood vessels that they observed in the back of their hands ("veins"), there are smaller blood vessels ("capillaries"). These vessels are located in between the cells and are responsible for the small bleeding that occurs when a person gets a cut that is not on a vein. They also acknowledged that these small blood vessels (capillaries) are invisible to the naked eye. In response to the alternative idea presented by the teacher, a student said:

> Mi: It doesn't have to go through them but like between them and then it could sink in through the walls.

From the transcript, we hypothesized that the student reviewed and modified her initial ideas. She changed her ideas from *blood cells leaving the big blood vessels ("veins") to blood cells sinking through the walls of smaller blood vessels (capillaries) to provide oxygen and glucose to the big toe cells.* This was confirmed by her later remarks.

The events just described contain the second Micro Cycle of the co-construction process of the circulatory system. (See Figure 5.) The students had an initial idea in which there was an inaccuracy from the scientific point of view (blood "sink in" through the walls of big blood vessels that they called "veins"). The teacher asked a few "hint questions" containing an alternative idea regarding the presence of small blood vessels (capillaries) between the cells. The counter argument presented by the teacher may have produced a mild dissonance in the students' minds. The dissonance appeared to have promoted one of the female students to review and to modify her model ("schemata tuning"). She changed her model from *blood leaving the big blood vessels* ("veins") to *blood sinking in through the walls of smaller blood vessels (capillaries)* to provide glucose and oxygen to the cells of the big toe. Even though she made progress by incorporating the smaller blood vessels (capillaries) in her model, she did not abandon her idea that blood crosses the blood vessels walls. The teacher had to examine that conception further. The other three students agreed with the female student's ideas.

Third Micro Cycle

The third Micro Cycle of the circulatory system began when the teacher focused the students' attention on another element of their models. In that portion, the students held an incorrect idea from the scientific point of view. The students believed that blood is able to leave the smaller blood vessels (capillaries) to provide oxygen and glucose to the cells of the big toe. The teacher provided the students with a counter argument to produce dissonance and construction. The teacher asked the students an "information-recalling question" to remind them of the content discussed during the previous session. In the previous session, the teacher and the students discussed the relative size difference among atoms, molecules, and cells. The teacher said:

M: OK, remember when we talked the other day about molecules and atoms and how tiny they were and they were much tinier than cells, right? And if this is a cell, [she draws on the board cells and atoms. In addition, she draws a blood vessels containing several red blood cells] here is the [much smaller] oxygen molecule, see how much difference that is?

Mi: Oh yeah.

M: OK, we can't even see a molecule with the microscope. So when I have these here what I'm talking about really is like this [she points at her drawing] and here is some oxygen on the blood cells. OK, so what do you think might happen?

Mi: Ah, hah

M: So here is oxygen and glucose…

Mi: I am thinking it [glucose and oxygen] goes through the walls. Because I mean like even if the blood did go into the actual cells, it [glucose and oxygen] still has go through the walls to get into the cells, so I am saying, it is not going to make a difference like floating around inside the blood cells.

The student agreed with the teacher about the recalled information about the relative size difference among atoms, molecules, and cells. After the teacher asked the students an "information-seeking question" to detect the state of the students' model. She said, "what do you think might happen?" The student answered her question by saying, "even if the blood did go into the actual cells, it [glucose and oxygen] has to go through the walls to go into the cell … like floating around inside the blood cells." From the student's answer, we hypothesized that the student reviewed and modified her previous ideas but not in the direction expected by the teacher. The student changed her ideas from *blood cells crossing the small blood vessels' walls (capillary)* to *blood cells containing inside oxygen and glucose crossing into the cells to provide them with glucose and oxygen.* The teacher seemed to have realized that the student did not comprehend that red blood cells are too big (compared to glucose and oxygen) to cross the blood vessels (capillary) walls.

The events just described contain the third Micro Cycle of the co-construction process of the circulatory system. The students had an initial idea in which there was an inaccuracy from the scientific point of view (blood crossing the walls of small blood vessels or capillaries). The teacher proposed a new idea by recalling information about the relative size difference among atoms, molecules, and cells. The new information may have produced mild dissonance in one of the student that caused her to review and to modify her model ("schemata tuning").

Even though she incorporated the relative size difference between cells and atoms in her model, she did not abandon the central idea that blood cells leave the blood vessels. Instead she added to her model that blood cells carrying inside glucose and oxygen were able to go even into the actual cells. From her answer we hypothesized that the student did not go in the direction expected by the teacher and she had to examine that error further. The other three students agreed with her points of view.

Fourth Micro Cycle

The fourth Micro Cycle of the co-construction process of the circulatory system began when the teacher used another girl's idea to build the model further. The girl asked:

> B: What if...when you hit like a vein.
> M: Uh huh.
> B: And you get cut, why it does it bleed so much if there's supposed to be the same amount of blood all around? Why does it bleed so much if you hit it?

The teacher tossed the question back to the students by using an "information seeking question" to detect the state of the students' models. The teacher said, "um, what do you think about that?" A girl answered the question by saying that some blood vessels carry more blood than other vessels. She said:

> Mi: I think some places it's traveling, like in my major arteries, it is like a river [she makes a strong noise with her mouth and moves her hands] and then like other parts it is like a stream [she makes softer noise with her mouth and new hands movements].

The teacher then asked the students an "information-recalling question" to introduce dissonance and construction by examining the students' understanding regarding the amount of blood that comes out when a person gets a blood vessel cut. She said, "Have you ever seen, one of those doctor shows when someone got cut?" The students narrated several experiences and agreed that when a person gets a big blood vessel cut he/she will bleed a lot more than if that person gets a small blood vessel cut. The teacher also recalled that a student had previously said about the heart pumping blood all the time. She said:

> M: Uh huh, but G you said something about your heart doing something constantly. What did you say it did?
> G: Pumps the blood around the body
> M: Pumps. So, if you have something constantly doing this [squeezed fist], squeezing the blood what is going to happen when you cut yourself in your arm?
> L: Is that how they stop internal bleeding, is to shut your heart down?
> G: It keeps pumping and then the blood keeps on coming out and then these little cells or whatever...
> L: That is why you have to…
> M: That is why you see a stream.
> B: So it [heart] just keeps pumping.
> M: Pumping because your heart can't stop, can't it? It has to keep pumping.

The students realized that a person would loose a lot of blood due to the heart's continuous pumping if he/she got a big blood vessel cut. With this new understanding in mind, the teacher asked the students to go back to the original problem that they were discussing. The problem was whether blood cells are able to leave blood vessels when they arrived at the cells of the big toe. The teacher asked the students a "discrepant question" that promoted dissonance in the students. The question caused the students to think about two contradictory ideas. The first idea was in respect to blood leaving the blood vessels and going into the cells of the big toe to give them glucose and oxygen. After the blood cells accomplished this function, they go back up to the heart. The second idea was regarding the continuous loss of blood when a person gets a big cut due to the continuous heart pumping. The teacher said:

> M: OK, so let's get back to this, all right, we got blood in here [pointing a drawing of a capillary vessel containing several blood cells inside] and it has a lot of blood cells. When you look the blood cells in the microscope, it is very good size. Do you think that these blood cells come out of the vessels?

[Silence]
Mi: No [quietly].
M: Let me ask you this.
L: Yeah [loudly].
M: If the blood cells came out of the vessels, wouldn't you run it [blood cells] out of them after a while?
B: Why?
M: Well, if they [blood cells] just keep going out there [in the cells of the big toe to provide them with oxygen and glucose], it seems that pretty soon, nothing will be going back up [to the heart].
L: Is that why old people start to wilt?
G: No.
M: [laughs] Very good question!!
B: L!
M: That's a good question.
L: I could say it another way?
M: Yeah, yeah.
Mi: But wilt…
M: What would happen to you?
L: You'd deplete.

The "discrepant question" (If the blood cells came out of the vessels, wouldn't you run it out of them after a while?) triggered a spontaneous question in one of the students. He asked, "Is that why old people start to wilt?" The question asked by the teacher, and the question asked by the student generated a long discussion within the small group explaining why people get weak as they get older. The teacher related the weakening process to the lack of iron in the blood, which is known as anemia. The teacher's question seemed to have produced a stronger dissonance in the students' minds. The students tried to clear up their contradictory ideas about blood leaving the blood vessels to provide glucose and oxygen to the cells of the big toe. In addition, they discussed the notion of the body running out of blood when a person gets a big cut. (For further discussion of discrepant questioning, see (For further discussion of discrepant questioning, see Rea-Ramirez & Nunez-Oviedo, January 2002). However, none of the topics brought up by the students to solve the contradiction between the two ideas were successful. To solve the mystery, the teacher provided the students with a *Small Piece of Information* to help them to fill in the "gap" they had in their model. She said, "the cells are big…" When the teacher presented the information, a female student immediately agreed with the new notion. They said:

> M: Right, good, OK, so these [blood] cells are big and you've got to keep them going. Do you think that they [red blood cells] are going into here [cells of the big toe]? You guys told me that they [red blood cells] are staying in here [blood vessel] and they were dumping what they needed
> Mi: That is what I am saying.
> M: OK, you need to convince some other people because I'm not here to agree with you.
> Mi: Are you saying that I am right?
> M: I am saying…
> Mi: Because I think I am.

From the transcript, we hypothesized that one of the female students reviewed and modified her previous ideas to incorporate the *Small Piece of Information* into her model. The student changed her ideas from *blood leaving the blood vessels* to *blood cells not leaving the vessels due to their size, and only transferring glucose and oxygen to the cells of the big toe.*

The events just described contain the fourth Micro Cycle of the co-construction process of the circulatory system. The students had an initial idea in which there was an inaccuracy from the scientific point of view (blood leaving blood vessels to go into the cells of the big toe to provide them with glucose and oxygen). To promote dissonance, the teacher asked the students to recall information about the loss of blood from a blood vessel cut. In addition, the teacher asked the students to recall information regarding the heart's role in pumping the blood around the body. The teacher then asked the students to put these two ideas together. They learned that when a person gets a blood vessel cut, that person may loose a lot of blood due to continuous heart pumping. On the other hand, the students argued that blood crosses the blood vessels walls to provide glucose and oxygen to the cell of the big toe. Thus the students held two contradicting ideas. The teacher appeared to have detected the contradiction and asked the students a "discrepant question." "If the blood cells come out of the vessels, would you run out after a while?" This question appeared to have created a strong dissonance in the students. The dissonance may have forced the students to review and modify their models ("schemata restructuring"). However, the students did not have enough background to fill in the "gap." For that reason the teacher presented the students with a *Small Piece of Information*. She proposed that blood cells do not leave the blood vessels, but they stay inside and transfer the glucose and oxygen into the cells of the big toe.

One of the female students (Mi) that was the most vocal in holding the idea that blood cells left the capillary walls changed her ideas almost immediately during the fourth Micro Cycle to what the teacher was proposing. The girl appeared to have repaired her model, and hence it was more in agreement with the scientific point of view. However, the other three students appeared not have acquired the same level of understanding. Two of the students (B and G) were most of the time in silence following the discussion carefully. They appeared to agree with most of the terms of the conversation. On the contrary, the third student (L) was not fully convinced of some of the ideas discussed by the small group in the fourth Micro Cycle. Therefore, the fifth Micro Cycle describes the efforts made by the teacher and the other students to provide him with sound evidence to repair his model.

Fifth Micro Cycle

The fifth Micro Cycle of the co-construction process of the circulatory system began when the teacher asked the student (Mi) to convince the other members of the group about the correctness of her model. The student used an argument related to the heart's function to persuade her teammates. She argued that the heart was not producing new blood but only pumping blood through the blood vessels. She said:

M: Then you need to convince them.
Mi: Because another point, your heart doesn't make blood your heart just recirculates it and gives it more stuff, so I am saying, like, if you keep giving your blood vessels to these and say they dissolve and like drop off the glucose or whatever you're saying they do. Do you know what I am saying?
L: Uh huh.
Mi: Your heart doesn't not make any blood
L: So how do people, like, donate blood?

The student's comment about the heart not producing new blood triggered a question from another student that appeared to have promoted dissonance in the teacher and the other students. He asked, "so how do people, like, donate blood?" From his question, we hypothesized that he believed that the heart was responsible for making new blood inside of the body. The students had a long discussion about how, when and why the body makes new blood. They tried to understand the question but they did not have enough background regarding the blood production process. For that reason, the teacher presented the students with another *Small Piece of Information* to fill in the "gap." She explained that the body produces new blood when red blood cells die after three months approximately. In addition, the teacher asked the students if the information provided made sense. The student agreed with what the teacher had presented:

M: OK, let me just tell you briefly that we don't need to worry about the making the blood here. The only reason your body continues to make new the blood is because these blood cells get worn out after a while they only last certainly a long time but it not because they are moving through here [blood vessels], OK?
Mi: So like
M: They just, I mean it is just anything else your skin cells get worn out and then you sift them off, OK? So don't worry about making new cells you don't worry about that, you just need to worry about what happens with these cells as they move through this [blood vessels].
Mi: hmm
G: hmm
M: Does it make sense to you? [dropping off glucose and oxygen for the cells of the big toe in the drawings]
Mi: Yes, yes it does.
L: Indeed.
M: OK, so now you got...

Mi: Should we agree that it [glucose and oxygen] comes from the heart.
M: OK, so you are saying that at some point they are coming through the heart.
Mi: I agree.
G: So do I.
M: OK, so at some point you are saying it [glucose and oxygen] comes from the heart, all right? ... OK, I'm going to put the heart in here [she draws the heart in an outline of the human body]. Is it all right for every body if I put the heart in here?
Mi: Yeah.

From the transcript, we hypothesized that the student (L) reviewed and modified his initial ideas to incorporate the new piece of information provided by the teacher. He changed his ideas from *the heart making new blood* to *the heart only circulating the blood (with glucose and oxygen) inside of the body*. In addition, he learned that *the new blood is made because red blood cells are dying constantly*.

The sequence of events just described corresponds to the fifth Micro Cycle of the co-construction process of the circulatory system. The students had an initial idea but there was a missing piece in their model (why the blood makes new blood). The absent piece may have produced a mild dissonance ("schemata tuning") in the students' minds. However, they did not have enough background to fill in the "gap" by themselves. The teacher presented the students with a *Small Piece of Information* regarding the reasons that the body needs to make new blood constantly. The information helped the students to review and modify their models. At this point, the four students appeared to have reached a general understanding of the main pieces that compose the circulatory system.

Later Steps of the Co-Construction of M_2

Five Micro Cycles were developed by the teacher to guide the students in building individual aspects of a model of the circulatory system. Throughout the Micro Cycles, the students appeared to have built most of the pieces with the teacher's support. The teacher asked the students to summarize, as a group, the intermediate model (M_2) of the circulatory system (*Stages Model Summary*). The summary may have helped the students to put together what they had learned to reach closure:

> M: OK, let's see if we can construct what this looks like from all everything that you have drawn together, OK? Because all of you got a piece of it, all right. What happens from the heart?
> Mi: Hum, the heart, um like distributes the glucose and the oxygen.
> M: OK, so it distributes through what?
> Mi: To the blood, vessels.
> M: OK, so it goes into blood vessels and then it comes down here to your toe.
> Mi: How does it [blood] know when to give it off?
> M: Oh, good question. What do you think?
> Mi: I think it gives up a little bit all along the way but it keeps pumping through, so eventually some gets down here or to the top.
> M: Ah.
> L: Could it be certain size veins let more blood out and they born with like maybe bigger veins in your legs and.
> Mi: Uh, what if you like have really big veins in the arms?
> M: That's that is an interesting idea. Why do you need that in some parts of your body?
> L: Because some parts of your body need more blood to function more
> Mi: Because they have more cells and the cells are more active.
> L: And then varicose veins are like making hurt because you don't have these big veins right? Or I'm totally lost.
> M: No you're not totally lost at all. Varicose veins are all another things. Basically a varicose vein is just a vein that…it does not...
> L: But it does not push the blood through.
> M: Right. OK, so we got the blood going out, [She points a drawing on the board] the heart pumping, blood going out to the toes, circulating around, coming back up, and going back into the heart.
> Mi: And the heart is getting its stuff to give to the veins.
> M: Uh huh, from where?
> Mi: From when you breathe and from when you eat.
> L: Veins are different sizes.
> M: OK.
> Mi: Good job!

From the transcripts, we hypothesized that the students put together most of the elements that compose the intermediate model (M_2) of the circulatory system with the teacher's support. The model contained the following ideas: the heart pumps blood through the blood vessels to distribute the glucose and the oxygen to the body's cells; blood does not cross blood vessel walls but it returns to the heart; the blood gets glucose and oxygen from what a person eats and when he/she breathes; blood vessels have different sizes. As it can be seen from the transcript analyses, the intermediate model (M_2) it is not a product of a sudden insight in the students' minds. But it emerged from five Micro Cycles that were put together by the teacher to help the students to review and modify their initial ideas over a period of time. The teacher initiated four out of the five Micro Cycles in this case.

Evidence for Co-construction

From the transcripts above, we have evidence that both the student and the teacher were contributing ideas to the model construction process and therefore we have evidence that this interaction was a process of co-construction, as shown in Figure 5. It appeared that the students contributed somewhat more of the elements (right or wrong) of the model than the teacher to the sequence of partially correct intermediate models. However, these were usually triggered by a question from the teacher. Also, the teacher appeared to have contributed ideas more directly when the students lacked enough prior knowledge to invent a model element, or when refining the model at the end using the animation.

Generating a More Sophisticated Model (M_3)

After the students generated the intermediate model (M_2) of the circulatory system, the researched presented the students with an *Animation* during the *Comparing the Student the Student and Scientist Models* phase of the Macro Cycle. While watching the *Animation*, we hypothesized that the students experienced additional Micro Cycles, which also involved mild dissonance ("schemata tuning"). The dissonance led the students to review and modify their ideas to a formal model (M_3) of the circulatory system.

To help the students to be aware of their own conceptual change, the teacher asked them to compare their final (M_3) and initial (M_1) ideas, and to modify their original drawings if they thought it was necessary. These activities were done in the *Adjusting the Student Model* phase of the Macro Cycle. By the end of the teaching of the circulatory system, all of the students completed their initial drawings by including the information they had learned.

The Micro Teacher and Student Cycles were also present in other segments of the teaching sequence. For instance, the teacher and the students developed four Micro Cycles when they were co-constructing models of the digestive system. They also developed five Micro Cycles when they were co-constructing models of the respiratory system.

Student Reasoning During the Co-Construction Process

This analysis has focused primarily on teacher activities in the teacher-student co-construction process. It should be noted that the process is one in which students are nearly constantly engaging in reasoning. The majority of teacher questions are open-ended and require students to iterate, compare, critique, and defend their own and other students' models. Students are able to reason about the structure of the human body and processes occurring within it through logical processes such as determining which structures would be able to perform a given function and which would not. For example, students are generally able to construct a model in which two tubes rather than one extend from the throat to the stomach and lungs after teachers question them about experiences such as choking and having food go "down the wrong way." Inference about form that can supply a given function constitutes the basis for much of the student reasoning which occurs with this teaching approach.

In addition, student-to-student interactions were involved in a considerable portion of the reasoning and model revision that occurred in the trials. On a number of occasions, students contributed correct pieces of models, analogies which could help other students understand important concepts, or critiques of their own and other students' models. In addition, as the curriculum progressed, all four students became more self-sufficient, volunteering ideas even when not prompted by the teacher. One of the students increasingly took on some of the teacher's facilitation roles, performing such functions as urging other students to "defend your model!" Thus student-student interactions played an increasing role in the co-construction process as students gained model criticism and revision skills and confidence.

Summary

Evidence that supports the presence of small cognitive cycles of model construction and criticism was presented in this section. The evidence presented here came mainly from the teaching of the circulatory system, however the same patterns were also found in other units of instruction.

The findings were described through three nested processes: Macro Cycles (outer process) Micro Cycles (middle process) and Teaching Tactics (inner process). Each of these processes constitutes a progressively finer level of description. The paper mostly focussed on the description of the Micro Cycles.

The Micro Cycles are more evident during the *Building on Student Ideas* phase of the Macro Teacher Cycle and were depicted as little circles in Figure 2. In this phase, the teacher helped the students to build a more sophisticated model (M_2) than their previous ideas (M_1). To do that, the teacher promoted several Micro Cycles. A Micro Cycle contains three phases shown in Figure 3. The outer diagram is called the Micro Teacher Cycle and the inner diagram, the Micro Student Cycle. By using several Micro Cycles the teacher and the students worked as partners to co-construct a series of intermediate models of the target for each of the problems detected.

The driving force from which the Micro Cycles appear to emerge is dissonance. The teacher used "dissonance and constructing producing tactics" created a mild dissonance ("schemata tuning") or a strong dissatisfaction ("schemata restructuring") in the students' minds. The dissonance seemed to have guided them to review and modify their ideas. Among the "dissonance and construction producing tactics" the teacher used several kinds of *Questions*, and *Recalled Life Experiences*. The teacher seemed to have used questions and recalled life experiences when the students had more background about the topic. When the students had less background regarding the content, the teacher presented them with *Small Pieces of Information*. The teacher also used small "supporting tactics" within the Micro Cycles to keep the reasoning process going and to detect the effect of the "dissonance and construction supporting tactics" were having in the students' minds. Among the "supporting tactics" the teacher used *Drawings, Thinking Aloud, Explanatory Need, Model Stage Summaries,* and *Teacher/Student Interactions*.

After the students generated most of the segments included in an intermediate model (M_2) of the circulatory system, they were presented with an *Animation* to generate an even more sophisticated model (M_3) of the circulatory system. To help the students to be aware of their conceptual change, the teacher asked the students to compare their final (M_3) and initial (M_1) ideas, modifying their initial drawings if they thought it was necessary. A summary of the entire processes described above was presented in Figure 4.

Conclusions

Students gained a significant understanding of human respiration as evidenced by comparing pre- and post- interview scores. It was observed that students did not passively receive the topic but they interacted highly with the teacher to build hidden structures of the human body. One of the main characteristics of this way of teaching is the large number of exchanges between teacher and student that contribute to the discussion. Rea-Ramirez (1998) called the process co-construction.

From this case study, we provided evidence for a process of co-construction in which both the student and the teacher were contributing ideas to the model construction process, as represented in Figure 5. We consider this way of teaching a middle road between purely teacher generated or student generated ideas. The teacher had an important role in helping the students to generate, review and modify their ideas through what we have called Micro Cycles.

The driving force of each of these Micro Cycles is a small episode of dissonance. The teacher introduced dissonance by selecting and coordinating carefully different kinds of teaching tactics. The teacher used "dissonance and construction producing tactics" to promote small or strong dissonance. The teacher used "supporting tactics" to keep the reasoning process going and to detect the effect that the "dissonance and construction producing tactics" were having within the students' models.

The teacher presented the appropriate "dissonance and construction producing tactic" only when the students were ready to receive it. We hypothesize that the process of promoting dissonance in small doses at a point where they were ready to repair the problem prevented the students from becoming overwhelmed or discouraged by too much dissonance at once. In this case, the students were willing to re-examine a small piece of their ideas at a time. Thus we suggest that piece-wise dissonance events were an effective tool in helping the teacher to deal with multiple misconceptions.

In order to know when the students were ready to receive the small episode of dissonance, the teacher was very aware of the students' ideas. During the co-construction process, the teacher acted as a detector of ideas and "gaps" in the students' understanding. In addition to detecting the students' ideas at the beginning and the end of instruction, the teacher located the students' ideas frequently during the instruction as well. Thus, this model of co-construction includes new ideas regarding the frequency with which the teacher should detect the students' ideas.

We hypothesized that model construction was not the product of a sudden insight in the students' minds, but resulted from an organization of activities that were described as nested processes. In the outer process, we postulated a Macro Cycle in which the teacher guided the students in constructing progressive intermediate models (M_1, M_2 and M_3) of the target. The modes of instruction were different in different parts of the Macro Cycle. At the beginning of a unit or Macro Cycle, the teacher asked "explanation questions" to detect students' understanding. At this point, the teacher did not criticize or encourage students to modify their conceptions. In the middle of the Macro Cycle, the teacher began to promote dissonance and modification. This took the form of questions, hands-on activities, and analogies. In addition, the teacher sometimes provided the students with constraints and counter arguments to guide them in the expected direction. At the end of the instruction, the mode of the teacher was similar to the beginning of the instruction. The teacher refrained from adding more information to the students while they were watching the animation and comparing their final and initial drawings.

We observed that the teacher allowing for student idea generation and modification caused student's misconceptions to be engaged, and discussed. We speculate that it also encourages a deeper level of processing than in traditional instruction and it allow them to own the questions being considered. For these reasons we suggest that the scientific model should only be presented to the students when they have generated at least two intermediate models of the content.

In the middle process, we conjectured the presence of several Micro Cycles in which the teacher promoted small events of dissonance to guide the students in the revision and modification of small segments of their ideas. Therefore, the success in introducing small events of dissonance may have depended in particular on two skills. The first skill was the teacher's ability to detect the students' models. The second skill was the teacher's ability to select the most adequate "dissonance and construction producing tactics" to promote dissatisfaction within the students' minds. The teacher helped the students to put together their ideas to build a more sophisticated model (M_2) than their initial (M_1) one. The intermediate model produced (M_2) may or may not be in complete agreement with the current scientific conception. In addition, several versions of the same intermediate model may coexist among the students. Thus we argue that through the Micro Cycles, the teacher helped the students to examine and repair inaccuracies, contradictions, and "gaps" in their understanding about a topic.

In the inner process, we hypothesized the teacher as a careful coordinator of teaching tactics able to promote the small dissonance events and to detect their effect in the students' minds. Thus the model describes strategies for coordinating several teaching tactics such as analogies and discrepant events that have often been treated separately in previous studies (Raghavan & Glaser, 1995; Raghavan, Kesidou, & Sartoris, 1993).

The ideas presented in this paper come from the analysis of the interactions of a small group and a teacher. Will the instructional models and mechanisms derived from the generative analysis of the small group be helpful to explain what can happen in a normal-sized class? A preliminary analysis of how model construction and evaluation might be promoted in large group discussion in full classrooms is provided in Clement (2002). What other mechanisms can explain the process of mental model construction in a full classroom? These and other questions are ongoing topics of research for us (Rea-Ramirez, Nunez-Oviedo, Clement, & Else, In preparation).

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VOICES IN A RESERVATION SCHOOL: A SONATA-FORM NARRATIVE FROM A PROFESSOR AND A DAKOTA PRE-SERVICE TEACHER ABOUT THEIR PROFESSIONAL AND PRACTICAL KNOWLEDGE TEACHING SCIENCE IN CULTURALLY RESPONSIVE WAYS.

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The Umo^{n}ho^n Nation Public School, with federal funding and collaborative support, is revitalizing Umo^{n}ho^n culture and language. Native American pre-service teachers are learning to teach Umo^{n}ho^n children using a standards-based curriculum incorporating Umo^{n}ho^n language and Umo^{n}ho^n culture aligned with the state's local renewal accountability plan. Narrative inquiry methodology was used to produce the final "Sonata-Form" illustrating the worldviews of a Dakota pre-service teacher and a university professor living on the Reservation and learning to teach elementary science in culturally responsive ways. The results indicate "… the belief that a firm grounding in the [Umo^{n}ho^n] heritage language and culture indigenous to a particular place [Umo^{n}ho^n Reservation] is a fundamental prerequisite for the development of culturally-healthy students and communities associated with that place, and thus is an essential ingredient for identifying the appropriate qualities and practices associated with culturally-responsive educators, curriculum, and schools" (Alaska Standards for Culturally Responsive Schools, 1998, p. 2).

There are too few Native American teachers in reservation schools. Many reservation community members feel that "Indian teachers would be more effective than white teachers [are] in reaching Indian children" (Abbot & Slater, 2000). Hiring Native American teachers to fill this request remains a problem. Over the past two decades, Native American enrollment in post-secondary institutions has increased 67 percent; however, these 127,000 Native American students are the smallest college enrollment population (Pavel, Skinner, Cahalan, Tippeconnic, & Stein, 1998; Pavel, 1999). These students tend to select business and health programs; therefore, the pool of Native American students who might choose teaching as a career is very small. The pathway to a good job is a good education; that's the "American Dream." But "Indians do not believe they will reap the same rewards, so why should the kids worry about what school will get them?" (Abbot & Slater, 2000). If Native American children had role models that they saw going off to school and getting good jobs, then this might provide motivational possibilities for them. Since the number of Native American students choosing college to seek a dream is small, the potential to increase native teachers in reservation schools may not fill the need for more native American teachers; then, Native American children will not have role models to help them be more concerned about school.

Previous research studies have explored ways to provide engaging and effective learning environments (Allen & Crawley, 1998; Kawagley, Norris-Tull, & Norris-Tull, 1998) that would increase Native American children's learning opportunities and positive attitudes toward education (Matthews & Smith, 1994). But many Native American scholars contend that non-natives should not be the ones conducting the research and writing about Native Americans because of the radically different world-views (Peshkin, 2000; Swisher, 1996). Non-native researchers tend to "interpret Indian life from within the broad theoretical frameworks, or United States or Western historical terms and generally place strong emphasis on expanding European economic or political activities" (Champagne, 1998). Others contend that there is room for both native and non-native scholars to collaborate, "within American Indian studies," (Champagne, 1998) "one does not have to be a member of a culture to understand what culture means or to interpret culture in a meaningful way." Still others argue for a development of a Native American pedagogy and indigenous identity, separate from critical race pedagogy, (Anglas Grande, 2000) which would be better sited to Native American communities. Native Americans have unique "grounding in the heritage language and culture indigenous to a particular place [that] is a fundamental prerequisite for the development of culturally-healthy students and communities associated with that place" (Alaska Standards for Culturally Responsive Schools, 1998).

Sleeter (2000-2001) contends that emancipatory research "empowers historically marginalized communities" making an insider-outsider distinction—Indigenous insiders, Indigenous outsiders, and External insiders—and membership in a group per se does not necessarily guarantee the one's viewpoint will reflect that of the group" (p. 235). Most non-natives do not think, act, or communicate like Native Americans. Just like most people do not think, act, or communicate about science-like scientists (Matthews, 1994), because Western scientific knowledge is a "product of the social enterprise" exclusive to a particular scientific community (Driver, Leach, Milar, & Scott, 1996). Lederman and Abd-El-Khalick contend that a particular science worldview is affected by the social and cultural context in which it is produced (1998, p. 21). Observations, interpretations, and explanations are filtered through the lens of the particular community's knowledge (1998, pp. 21-22); and the particular community determines: (a) phenomena that are worth researching, (b) acceptable questions to ask of the phenomena, (c) appropriate research methodologies and adequate instrumentation, and finally, (d) relevant and admissible evidence (1998, p. 22). Potentially then, the Native American science worldview is affected by the social enterprise, heritage language, and culture indigenous to a particular place and context in which it is produced.

Since most people do not think, act, or communicate like Native Americans, then, potentially, the stories from the professor and the pre-service teacher in this paper will present information supporting that claim that "heritage language and culture indigenous to a particular place is a fundamental prerequisite in determining the (a) indigenous ideas that are worth researching; (b) acceptable questions to ask of these indigenous ideas; (c) appropriate research methodologies and adequate instrumentation; and (d) relevant and admissible evidence to produce the indigenous pedagogy of that particular Native American Community" (Anglas Grande, 2000, Alaska Standards for Culturally Responsive Schools, 1998, Lederman & Abd-El-Khalick, 1998).

Background

The Umo^{n}ho^{n} Nation's language and culture are endangered. In the summer of 1999, the United States Department of Education awarded the university a bilingual career-ladder award to help the Umo^{n}ho^{n} Nation's Public School revitalize Umo^{n}ho^{n} culture. This award supports a five-year collaborative effort among the Reservation school, the Indian Community College, the university, and the State's Department of Education (DOE) to certify thirty Native American para-professionals as bilingual (Umo^{n}ho^{n} and English) teachers. Beginning with the Fall 1999 semester, the first cohort of pre-service elementary teachers began the process of learning to teach Umo^{n}ho^{n} children using a standards-based curriculum and incorporating Umo^{n}ho^{n} language and Umo^{n}ho^{n} culture aligned with the State's Local Renewal Accountability Plan. The pre-service teachers are entering the culture of the Reservation school as new professional teachers and re-entering their original culture because they want to make a difference on their Reservation; they want to increase learning opportunities for Indian children from their newly emerging professional teacher identity. The recent fall 2001 report from the state's DOE summarizing the students' performance identifies the lowest scores in the state are from reservation school students. These scores seem to indicate a tension for the reservation schools attempting to meet the cultural needs of Indian children while attempting to increase learning opportunities for Indian children. The pre-service teachers and the university are ensconced in these dynamic contextual tensions.

Objectives of the Study

This paper focuses on experiences between one Santee pre-service teacher and a university professor. The purpose of this research study was to collect and analyze the stories about learning to teach elementary school science. The stories describe experiences and intentions while learning to teach culturally responsive elementary science in the Reservation school.

The unique contribution from this paper is that it provides stories for Native American and non-native scholars to discuss the conceptions and misconceptions about indigenous Native American science—what does indigenous culture mean to different individuals engaged in educational experiences with Native American students, and how do we teach in a culturally responsive manner indigenous to a particular place? The stories from this study may provide opportunities for Native Americans to believe in possibilities and to reap the rewards of a good education. Cook-Lynn (1998) contends that "how the Indian narrative is told, how it is nourished, who tells it, and the consequences of its telling are among the most fascinating—and, at the same time, chilling—stories of our time."

Analytic Method

The Nature of Stories

The oral tradition of storytelling is perhaps the oldest and most powerful tool for teaching and learning. It is not a written language, but an oral transfer of history and knowledge (Chambers, 1970; Sawyer, 1982; Parker, 1989). The stories told by Native American communities are particularly significant for communication about culture, heritage, language, and ways of knowing and doing. Stories, as defined for this research study, are narratives told orally to recall events and describe experiences about people in a setting doing something for a purpose. All people tell stories; telling stories helps both the teller and listener to think about and understand individual thinking and actions (Bruner, 1986, 1990; Polkinghorne, 1988; Ricoeur, 1991). Elders tell sacred stories about Umo^{n}ho^{n} language, heritage, culture, and values; Umo^{n}ho^{n} families tell personal stories about family life activities; pre-service teachers and the professor tell stories about their experiences learning to teach in culturally responsive science in the Umo^{n}ho^{n} Reservation school.

Stories in Narrative Research

Collecting stories has emerged as a popular form of interpretive or qualitative research (Gudmundsdottir, 1997). It has rapidly gained legitimacy in education and has flourished at research conferences (Louden, 1998; Taylor & Geelan, 1998; Wallace, 1997; Ollerenshaw & Creswell, 2000), in professional development activities in schools (Clandinin & Connelly, 2000) and in educational research journals (Venville & Milne, 1998).

Narrative research has gained increasing popularity in education and the social sciences as evident from numerous publications (e.g., Clandinin & Connelly, 2000; Lieblich, Tuval-

Mashiach, & Zilbert, 1998; McEwan, 1997; McEwan & Egan, 1995; Riessman, 1993). Researchers and educators collaborate to understand school experiences (Connelly & Clandinin, 1990) through narrative inquiry activities. It provides a "voice" for teachers and students (Errante, 2000), and it places emphasis on the value of stories in all aspects of life (McEwan & Egan, 1995). Clandinin and Connelly are attributed to the increasing emphasis on narrative inquiry in educational research; this form of qualitative inquiry has deep roots in the social sciences and in the humanities (Casey, 1995/1996; Marshall and Rossman, 1995; Cortazzi, 1993; Connelly & Clandinin, 1990). Design and procedures for finding storytellers and collecting their stories have emerged from anthropology, oral history, folklore, sociology, cultural studies, psychology and psychotherapy.

Design and Procedures

This research study incorporated a three-dimensional space approach based on Clandinin and Connelly's (2000) description in their text, *Narrative Inquiry*, and the Problem-Solution approach (Ollerenshaw and Creswell, 2000, 2002) for narrative analysis. The basis for the three-dimensional approach is Dewey's philosophy of experience, which is conceptualized as both personal and social interactions. This means that to understand people (e.g., teachers and students), one examines one's own personal, internally driven intentions and past experiences—personal practical knowledge, as well as social interactions, actions and reactions with other people—professional knowledge landscapes—that occur in a place or context, such as a school classroom or on a reservation. Knowledge is constructed from both personal and social interactive experiences; experiences grow out of other experiences and lead to new experiences. The Problem-Solution approach adds another layer to understanding experiences through a process of sequencing an individual's actions to determine a turning point in the events. The basis of this approach is "narrative thought." Yussen & Ozcan (1997) describe "narrative thought" as any cognitive action—reflecting, imagining, writing, telling … about people in a setting doing something for a purpose."

Data Sources

Archival materials (e.g., pre- and post-assessments, assignments, teaching plans, teaching observations, and letters) from the regular methods course were collected. The pre-service teachers were provided an opportunity to give their consent to allow their class materials to become part of the professor's inquiry into culturally responsive teaching. Regular methods class discussions and individual interviews were audio taped and transcribed.

The transcripts and archival materials have been read and re-read to get a sense of the data. Major themes and sub-themes that emerged during the coding process were "restoried" to create the final story that combines the personal and social interactions of the pre-service teacher and the professor on the Reservation. The professor discussed and negotiated the meaning of the stories with the pre-service teacher.

The results, which are presented in the Findings, incorporate Sconiers and Rosiek's (2000) sonata-form case study as the reporting structure, and Van Maanen's Confessional Tales (1988) as the reporting style to describe Connelly and Clandinin's (2000) professional knowledge landscapes and personal practical knowledge differences of the professor and the Santee pre-service teacher. Both the sonata-form structure and the confessional-tale style work together illustrating the epiphany, or how things changed from the beginning to the end of the narrative research study.

Sconiers and Rosiek (2000) adapted the musical sonata for their Fresno case studies. The sonata comprises (Boynick, 1996; Sadie, 1994) three main parts—exposition, development, and recapitulation. The "Exposition" expresses first, the main melody; second, a secondary melody; and third, the Coda returns to the main melody again with variations. The musical composition explores the melodic themes in the "Development" and is characterized by multiple musical tensions, and finally, foreshadowing the climax, a double return to the main melody occurs in the "Recapitulation" with emphasis on the secondary melody. The following summary presents

Sconiers and Rosiek's (2000, p. 398) adapted description of the sonata-form narrative structure for their case studies and provides an overview of the findings for this narrative study.

Exposition

I. A classroom episode on the Umo^{n}ho^n Reservation characterizes the theme (main melody) of the story from the very first line.

II. A description of classroom activity illustrates the professor's professional knowledge landscape, instructional philosophy, and culturally responsive intentions (main melody).

III. A new description of the situation follows in which instructional intentions of the professor come into conflict with the pre-service teachers' life experiences (secondary melody). This includes a description of the tensions and the professor's affective response to the experience (returning to main melody).

Development

IV. Moving away from the experience, the professor reflects on her understanding of one pre-service teacher's personal practical knowledge and professional knowledge landscapes on the Umo^{n}ho^n Reservation.

Recapitulation

V. Returning to the classroom experience, the situation's meaning is now changed from the exploration into the pre-service teacher's experiences.

VI. The climax weaves reflections and new questions from a new understanding about science, teaching, and cultural contexts indigenous to the Umo^{n}ho^{n} Nation.

The Findings

Exposition

I. Cultural Matrix – Identifying an Umo^{n}ho^{n} Worldview

"You're stealing our culture," Sam accused the professor.

"How did we get to this point?" the professor thought, when the accusation came out of the blue, like a tornado rolling across the plains after an intensely hot late summer afternoon, destroying the homesteader's farm. This afternoon, the pre-service teachers worked in small groups consolidating information collected from reading different text materials, and interviewing people and the Elders about Umo^{n}ho^{n} culture and Umo^{n}ho^{n} science. The information had been used in a large group discussion to develop an Umo^{n}ho^{n} information retrieval matrix. The matrix cells contained cited references and cultural ideas. The cells also contained cited references and big ideas that potentially the pre-service teachers could use to develop science units—ideas about, animals and plants, habitats and dwellings, earth and sky, and work tools and musical instruments.

II. Cultural—Intentions, Tensions, Conceptions, and Misconceptions

Professor's Professional Knowledge Landscape

Who could be better suited to live on a reservation teaching Indian pre-service teachers how to teach elementary science than a female professor, who had taught K-6th grade science for twenty years, was adopted by and studied with a Seneca grandmother, and who used real world field experiences, Seneca traditional activities, and storytelling to teach and assess science inquiry? I am flexible, build relationships and interact with people easily, and respect and embrace Native American traditions. Some Native American ways of knowing and doing were part of the underpinnings of my elementary science teaching rationale and career.

I spent my first year at the university meeting with individuals from the Reservation and those who have worked with the reservations in the state developing the federal grant to support the reservation collaborative work. During the following year, after the grant was awarded, I collected articles and books, read information, and continued to talk to individuals from the Reservation to learn as much about the Umo^{n}ho^{n} culture as possible. I was also engaged with multiple parts of the grant work, prior to living and teaching on the Reservation, e.g., I conducted the selective admission portfolio sessions, and I attended activities that were held on the Reservation, and met with the pre-service teachers when they came to the university for special activities. I communicated with instructors who taught on the Reservation for the first year of the project to gain an understanding of the pre-service teachers' needs and to increase my understanding of the Umo^{n}ho^{n} culture indigenous to the Reservation where I would be living and teaching.

We held classes in the Teacherage across the street from the Reservation school. The university and the Reservation school made an agreement that this apartment would be designated as the university classroom for the pre-service teachers; the university supplied the furniture from the campus's overstock-warehouse. The apartment had a large kitchen that the pre-service teachers would use for making lunch, transitioning between teaching at the school and taking the university classes. The kitchen served as a mailroom and communication center between the university, the school, pre-service teachers, and instructors. The living room/university classroom contained eight rectangular folding tables, table lamps, and an assortment of folding and stuffed chairs. The three bedrooms were converted into an office, a computer lab, and a resource room, which also contained a futon so I had a place to sleep; the bathroom was across the hall from the resource room.

The week before classes began, I took many of my teaching supplies from my university classroom to the Teacherage and stored them in the resource room. I spent time rearranging the living room in a way to resemble, as much as was possible, an elementary classroom. I developed supply centers, learning centers, and a larger group-gathering place; given the physical environmental constraints, the seating was arranged in a circle to accommodate a motivating science-learning environment. I found Umo^{n}ho^{n} language posters stacked with papers in a closet, and a tribal circle poster, both of which I displayed along with a poster of the state's topography, plants, and water resources creating a learning environment indigenous to the natural environment of the Umo^{n}ho^{n} Reservation.

Instructional Philosophy

'Tell me about an activity and I'll forget, show me an activity and I might remember, but let me do an activity and I will remember' illustrates my philosophy of teaching. Theories and practices that I wanted pre-service teachers to remember I synthesized and embedded in some type of activity for them to do.

What is important for elementary pre-service teachers—to know and to do—to be proficient teachers? Intensive debate and discussion led to the 1992 Interstate New Teacher Assessment and Support Consortium (INTACS) guidelines, developed by the Council of Chief

State Officers; these guidelines have been adopted by many states for new teacher licensure. The following five main categories illustrate my intentions and outcome-goals for pre-service teachers, which align with the INTASC guidelines. 1) They must have knowledge of indigenous culture, human development, content, and planning. 2) They must continually learn about children, and adapt instruction to meet each and every individual child's needs. 3) They must teach and communicate using multiple instructional strategies creating and managing the learning environment in ways to motive children's curiosity for inquiry. 4) They must inquire, continually growing through professional activities, assessment of children, and systematic reflection and revision. And finally, 5) they must collaborate and develop partnerships with peers and the indigenous community.

I model a facilitators role as pre-service teachers do the activity, I hand out clear assessment criteria via templates, and I provide opportunities for pre-service teachers to work together, to construct, and to apply these outcome-goals in ways that work for each individual pre-service teacher, with their cooperating teacher in that particular school-classroom experience.

The first class day, after we spent time building introductory relationships, using storytelling and a new game activity, I modeled a learning cycle and guided inquiry activity. I presented a story, modeling storytelling as an advance organizer to engage pre-service teachers' questions asking about the science concept—which was the theme of the story. An activity bag provided opportunities for the pre-service teachers to explore the objects specifically selected to help them construct a new understanding about the science concept. The pre-service teachers worked in small groups reading specifically selected articles about the science concept. I moved around the room, modeling the use of multiple questioning strategies, listening to their conversations, and asking questions to encourage reflecting and thinking. Then a consolidation activity provided opportunities for them to reflect on and articulate their thinking about the science concept, while interacting with each other, the articles, and reflecting on their prior experiences and the most recent experience with the objects from the activity bag.

The next day, I presented a storytelling workshop so pre-service teachers could learn how to tell stories that incorporated the previous day's science concept in a way that would be meaningful for children's learning. The annual Pow Wow was scheduled for the next five days; so it was no surprise that many of the pre-service teachers' stories incorporated a Pow Wow setting or context. However, their passion, creativity, and expert ability as novice storytellers to create culturally relevant science stories did surprise me. Throughout the weekend and the next few weeks, many of the pre-service teachers enthusiastically shared their experiences about telling stories to children in the classroom and how the children and the teachers responded positively.

The first day's experience concluded with an assessment, which was the same assessment used directly after the storytelling to pre-assess their thinking; this post-assessment would be used to compare any change in the pre-service teachers' thinking about the science concept as a result of the experience. After the first two consecutive class days, the pre-service teachers had an opportunity to anonymously share their perceptions, concerns, and experiences on a written evaluation form. I systematically collected conceptual assessments and evaluations every two days. I sorted and classified the ideas that emerged so that I could incorporate their ideas into the next class session.

The first two days of class seemed to be a success; the pre-service teachers commented that they liked sitting in a circle. The pre-service teachers saw a lot of possibilities and were already applying storytelling with Umo^{n}ho^n children in the Reservation school. They liked the hands-on-science activities; however, some pre-service teachers explained that since they belonged to a particular tribal clan, there were certain taboos that prevented them from engaging in certain activities, e.g., "… like with anything that crawls." Other pre-service teachers commented that they wanted more culture incorporated into the science class. Still other pre-service teachers commented that they had been seeking the Elders to learn more about language and culture. Some pre-service teachers shared their concerns that the Elders should be the ones to teach the clan information to their children. The information should not be shared in school. There seemed to be a tension amongst the pre-service teachers about what was culturally appropriate and what was right or wrong for them to teach to other people's children in the Reservation school. So I decided that I could possibly incorporate their requests and concerns, while modeling and teaching about the social community of science and the use of multiple and reliable resources and references.

Culturally Responsive Intentions

As the semester progressed, the pre-service teachers had been drawn to the poster of the Umo^{n}ho^n Tribal Circle on the classroom wall. During the previous four weeks of class discussions, their concerns about each other's actions, using or not using cultural aspects in their teaching, indicated to me as a teacher, a potential their lack of self-confidence, lack personal understanding, and/or consistency amongst themselves about what could be taught, and if anything should be taught, about Umo^{n}ho^n culture to Umo^{n}ho^n children in school; I perceived that this tension was far reaching. The tension existed between the pre-service teachers; they perceived that tension emerged from interactions with teachers and administrators in the school, and from interactions with Reservation community members. I wanted to help them develop a professionally supportive environment amongst themselves so that they could encourage and support one another as they moved through these tensions and attempted to use different culturally responsive practices in the school.

Because the poster caused many students to muse, "I would like a copy of that for my classroom," I reflected that the poster might be an important focus. If the poster was used as a learning context to help them identify what was important about Umo^{n}ho^n culture to incorporate into their teaching, and each pre-service teachers developed an Umo^{n}ho^n Tribal Circle poster specifically designed with cultural elements they felt were important for the classroom where they were teaching, then they might begin to articulate more clearly for themselves what they felt comfortable teaching and what was important about Umo^{n}ho^n culture for them to incorporate into their teaching. As a community, they could work together, collaborating and problem solving as they identified important and relevant cultural ideas for their teaching.

I thought that if they wanted, I could take the pre-service teachers' posters back to the university and have the Design Center enlarge, mount, and laminate their posters so that they could display their personal poster in their classroom. What I didn't take into account was that articulating appropriate Umo^{n}ho^n cultural teaching created yet another tension for the pre-service teachers. I perceived that their fear of offending the Umo^{n}ho^n community, their insecurity and/or lack of knowledge about Umo^{n}ho^n culture when teaching culture in the classroom was a burden that many pre-service teachers were not ready to carry. Some pre-service teachers turned this burden back onto me. This reaction took many forms. For Sam, he accused me of stealing the culture and taking it back to the university. For me, the collaborative informational matrix and professional supportive community activity took an unexpected turn and caused more tension for the pre-service teachers. Because I was living by myself on the Reservation, I had no personal peer-support community as I developed new possibilities to move the pre-service teachers through this stage of disequilibrium.

I returned to the university over the weekend. I pulled many reference materials and articles that I had been collecting to increase my knowledge of Umo^{n}ho^{n} culture, and I made reading packages for small work groups. An elder told me that in Umo^{n}ho^{n} culture there is only one source of information—from the particular clan leader. Within the Umo^{n}ho^{n} tribal circle, some clans no longer have a living clan elder. Since there are limited numbers of elders, the Umo^{n}ho^{n} Cultural Center encouraged the pre-service teachers to connect with the elders in the community to learn more for their cultural teaching background, then I felt that I needed to provide opportunities for the pre-service teachers to articulate a cultural position so that they might begin to think about "appropriate qualities and practices in their teaching associated with culturally-responsive teachers" (Alaska Standards for Culturally Responsive Schools, 1998, p. 2).

I felt that developing a cultural position for their professional knowledge landscape was a tension for the pre-service teachers. As the semester progressed the pre-service teachers shared stories reflecting their diverse —insider/outsider— personal knowledge landscapes: some married into the Umo^{n}ho^{n} culture from other Nations, some were raised and lived only on the Reservation, while others were raised in large cities and returned to the Reservation only recently. The pre-service teachers, due to missionaries and/or boarding schools, have different religious positions—Mormon, Christian, Native American Church, and Traditional Native. Those preservice teachers who are Umo^{n}ho^n have different clan positions within the hierarchy of the tribal circle and have different bloodline percentages. Because of these multiple positions and other variables, the pre-service teachers hold different right and wrong beliefs about cultural positions—how to contact the Elders, the cultural center, what and/or if culture should be taught in school, and who should be doing the teaching. Religion and background experiences gave way to the pre-service teachers' personal practical knowledge.

The pre-service teachers' personal practical knowledge about their culture has emerged over generations. The state's Indian Commission has archived the history; since the 17th century the Umo^{n}ho^n Nation's history reflects oppression, struggle and distrust from interactions with French fur-traders, the British, and the United States Government. Displacement, disease, conflicts, treaties and broken treaties, resource cessation, and diminishing reservation land by encroaching white settlers all attribute to the complex Umo^{n}ho^n culture, customs, economics, and lifestyle of the present. Umo^{n}ho^n culture is evident in the annual Pow Wow, and the Reservation school's sporting events as the way to gather, and celebrate Umo^{n}ho^n culture. Yet, within this context there are individuals who are trying to revitalize the Umo^{n}ho^n culture and language.

> "People here don't know how to help themselves," Sam confided to me as we walked through the Pow Wow grounds after the first week of classes.
>
> "I hope that I am able to find a way to help the pre-service teachers help the children help themselves," I responded earnestly.

I had perceived that I was building relationships and identifying the pre-service teachers' needs; yet, here was Sam, after four weeks of classes, accusing me that, "You're stealing our culture!"

Some pre-service teachers felt discomfort after Sam's accusation and individually came up to me after class to share stories about their childhood experiences growing up on the Reservation. I was moved by the intensity of the class and by their personal self-disclosures and personal stories of sacrifice and struggle.

Rose came to me after class and asked me, "What are you doing for dinner?" When I told her I would make something at the Teacherage, she invited me to her home to have dinner with her husband and their three children. She is from the Umo^{n}ho^{n} Reservation and her husband is from another reservation. They are both very traditional. That evening at dinner they shared, and modeled with their own children, their perspectives about culture, children, and teaching. Rose and her husband both agreed, "the pre-service teachers need to come to their own understanding about culture so that they can feel comfortable teaching culture in the school."

After dinner I returned to the Teacherage; it was dark and late, and there was a knock at the front door. Feeling a little uncomfortable from the day's tension, I cautiously peered out the door, and there was Delberta standing on the front step. "Can I come in for a little while and talk?" she asked.

Delberta entered the Teacherage, we sat down at one of the tables in the classroom, and she shared, as often she did, the thoughts that she had been working out in her mind.

> "I went to my grandmothers [husband's mother and grandmother] tonight to talk with them. I didn't want to say anything in class, but I did not agree with those who were upset today."
>
> "Yes, tradition tells us that the responsibility of teaching and passing on culture to our children is the responsibility of the elders," my grandmothers told me, and then they said that, "Anyone who knows anything about Umo^{n}ho^{n} culture is up on the hill [in the cemetery]."

> "If we want to make any changes here in the school, we must teach culture and language to our children, because if we don't, no one else will do this teaching."
>
> "My grandmothers think that we, the pre-service teachers, are the hope for our people," she said.

Development

III. Professional Knowledge Landscape from Personal Practical Knowledge

Delberta's teaching rationale evolved from her life experiences. She is a Santee woman married to an Umo^{n}ho^n man. She has nine children ranging from 1 year to 16 years; one child is autistic. Delberta says she knows about teaching, not directly from education courses but because, "I am a mother." January, 2001, as she began her student teaching, all nine children came down with chicken pox. Yet with numerous personal, family, professional, and cultural experiences that might distract her from her obtaining her Bachelor of Science degree in elementary education with an emphasis in Umo^{n}ho^n Language and an elementary teaching certification, August, 2001, she graduated with honors. Delberta now holds a teaching job, and is the cultural director for her reservation school. This sought-after degree has been a quest down a long road for Delberta, since she was nineteen years old. She is passionate in her belief that the lack in emphasis for education is what is "crippling native children." Delberta thinks that the past is the key to educating native children in the present.

> Science, for Native Americans in the past, was not something to be studied; science was life. Native Americans lived in balance, because if they took too much of one thing, the entire system would be out of balance. Their lives depended on their observations and knowledge of the natural world. The entire child's

> education evolved around knowing the religious and social customs, native plants and remedies, and respect for the elders who taught them about survival. This education ensured the survival of the child and the tribe. Our children need to learn about nature and the environment. They need to learn how to live in harmony and take care of nature in order to survive. Our lives are different, but the theme of education is the same, to ensure the survival of the child and the survival of the tribe.

Delberta's teaching incorporates her understanding of content and cultural indigenous to a particular place, and she conducts assessment of children's understanding prior to teaching a unit that is aligned with the national standards and educational reform.

> We [the fourth-grade class] began a unit on the Great Plains. We were reading a book and talking about Laura Ingalls Wilder and the pioneers. The book, it made it sound like Native Americans just kind of popped out of nowhere, and it wasn't teaching that background; so with my knowledge of Native American history, I asked the children, "Where do you think Native Americans came from?" "Who do you think was here before the pioneers?" And they thought, "cavemen," so, I kind of laughed, but I didn't want to, you know, make them feel dumb or whatever. So, I asked them, "Well, where did you come from?" They said, "From my parents." "Well, where did they come from?" So, we went on until they went back several generations. Then they realized that their leaders perpetuated that path of pioneers. And then, I asked them, "Well, where do you think they lived?" And then it hit them; "They lived here." I said, "Yes." They weren't being taught that

> in the book. So, I looked up the standards and I thought, well, it's Native, it would be in [the states'] history and I will incorporate their own Umo^{n}ho^n history into that.

Delberta continually learns about children and their learning styles as she adapts instruction attempting to meet each and every individual child's needs. She teaches science using nature and the environment for language development.

> I could send our different levels of learners outside to observe birds. For one little boy, I would write what he saw because he was unable to write. He wanted to participate and so I had to explain it to the other children, he can't keep up with his writing so I'm going to help him. There were some other ones who could write, so when we went out, they did their own writing, and I helped out the ones who needed help. We were sitting out there observing the birds; I would ask them, "What do you see?" "Well, I saw an American Robin on the Head Start root," or "We saw four birds on the ground looking," or "We saw a bird with something in its beak making a nest." When we got back inside, he would hurry up and go through the book, flipping through the book while everybody was looking, and we found out that it was a house sparrow. Another boy was copying. He got frustrated. I had him copy it and he tried to write. I wanted him to write what he saw, but he was frustrated with it and he walked away, so I tried something else. I said, "Well, I'll write one and then why don't you write one?" and that wasn't working. So I had to try other strategies. One little boy is really good with the math, reading, and writing, but when it came to making the posters, now, he

> struggled with it. So, I let one of the other little boys help him do his posters. They all were able to learn something from this, and I learned that from the way that they've learned that I was able to engage all of the learners from all different levels.

Delberta incorporates content knowledge, knowledge of learning theories, knowledge of individual children, integrated curriculum goals, and relevant cultural and community issues in her teaching.

> Storytelling has been a traditional way of teaching and entertaining our native children at home. This semester [during science methods] I have had the opportunity to use this part of my culture in the classroom to teach science and math. Initially the [third grade] students tend to be inattentive but when I told them a story that they were able to relate to socially, this captivated their attention. I was then able to incorporate how we could learn about science through our surrounding community. I chose to teach sound because it is a relevant science concept that my people heavily rely on in our culture.
>
> When a person wants to learn the songs and instruments of our culture they cannot go to a book to learn [this information]. They have to listen and memorize the music as it is being played or sung. So goes the same for the ceremonies and traditions, they are passed on orally. All our ceremonies and tradition have songs and music that go along with them and these instruments are made form natural resources that come from the surrounding environment. These areas covered in science can be applied to our traditions and help keep our culture alive and allow it

> to thrive in our students. With this the students are able to identify whom they are, keeping their confidence and self-esteem strong. This will contribute to their desire to learn and see the value of education.

Delberta's culturally responsive classroom management techniques illustrate how she motivates Umo^{n}ho^n children for learning and uses developmentally appropriate strategies, relevant materials, and cultural practices.

> My classroom management technique . . . I've had to talk to them a lot about relatives. I really had a hard time getting them, to stay with their work. I work with them like with my own children. One student was giving me a hard time, I went to his grandmother and we talked. I also go to the other Elders and . . . my grandmother; I talked to her and I told her about the problems I was having. I said, "I know that you believe that you don't discipline other people's children." "And I'm really having a hard time," and she told me, "Make that relationship with them. Let them know where you're at because they're not going to disrespect their own relatives, and you have to make that relationship with them." And so, I've been really trying to use that in the classroom . . . See, and it's so ingrained in my mind, you know, that you don't discipline other people's children. But that was really hard, because that's something that . . . in Native American culture . . . parents are really protective of their own, ... you don't discipline other people's children because it can lead to a family feud, and so . . . that was hard for me. Among my people respect and dignity are very valuable. Even if a person has nothing (materially), they will have respect and dignity. Everyone is deserving of

> them. If you are related to someone you will always show respect for that relationship. My people have a ceremony just for making relationships. It is very important in our culture.
>
> In teaching, I am a firm believer of having respect for one another. I teach this to students by making a relationship with them. When I speak to children or before I teach, I always make sure the students are aware of our relationship. If I do not know the child, I will ask them their name and make a relationship with them. When I am at school, children always call me auntie or they will try to find out if we are related somehow. This is very important and special to a child, to be related to someone.

Delberta's "firm grounding in the heritage language and culture indigenous to the Umo^{n}ho^n Reservation" is how she demonstrates use of Native American cultural values, language, song, and stories as a teaching strategy for managing the classroom and the 'development of culturally-healthy students.'

> When I talk to them [the children] in their language, it seems to stop their behavior that they're doing. I sang them . . . I tell stories, and now they know that I'm going to tell them stories. "Tell us a story," they say, and it seems like that works to get them into what we're going to talk about. The other [half of the] class had band and [those who were left] were arguing about something and I told them, "You don't speak to each other that way." I said, "You know…" and I told them a story about the little girl and I sang them a song. Well, now, it's, "Ms. Lyons, sing us another song." And it seems to change their attitude in a way, if they're

> misbehaving or if they're not following along … I can't explain it, … because when I was singing, one little boy laid on the floor. It was like he was sleeping, like a little baby and the other children, they're smiling. It kind of embarrasses them, but they enjoy it, too.

Delberta systematically reflects and revises her teaching practices so that she can provide opportunities for children to learn about themselves, their heritage, their culture, and their language so that they may learn to survive and be successful.

> Well, the first time I was in the classroom last semester, I did not do anything. I just sat there, and I just kind of ignored the behavior because I was afraid of it. I can't let these children do that. I did observations, daily observations and I recorded how I spoke to the children. I could see it within a month, I was starting finally to talk to them about their behavior and appropriate behavior and … and [I am] always trying to connect it [behavior] to their history. Always trying to connect it to their culture, so, that's going to, make them learn in a classroom different because there's a standard that they're going to have to meet and that standard I'm going to teach to them the standard of their elders. I reflect on that and I try to improve on it all the time, trying to get them, to where they need to be, where they're going to be able to be successful learners in the classroom.

Delberta continually inquires through professional and personal activities to increase her professional knowledge landscapes and personal practical knowledge.

> Last year I volunteered to go on the buffalo hunt because I thought it would be a good experience for me to learn. I kept a daily journal of where we went and the different things that happened, and I was able to develop a relationship with the

> other teachers, with the children and the people of the community that attended and participated in that trip down to Kansas.
>
> We also went to Sioux Falls, South Dakota, and I shared my science unit and storytelling at the National Indian Education Association Conference. I felt such a power there that is indescribable. All I can say is it choked me up to see my people so beautiful and intelligent. I kept thinking about how we were so poor and pitiful being driven onto reservations not knowing our future. It made me feel safe and secure just seeing how far our people have come. I think I was feeling the power of the human spirit in us and how resilient it is. All the things that I experienced there helped strengthen me in my journey to change the way I do things and think about things. I know I am not alone in that journey and there are resources out there to help me.

Delberta describes the tension for her professional knowledge landscape and personal practical knowledge—professionalism vs. sacrifice.

> But, Yes, it is hard for me to feel professional because when I see the word professional, I see that I have to make myself into a white person. That has been very, very hard for me, like, to overstep the bounds to discipline other people's children, to sacrifice my own children, to get to the school, leave my baby at home when he's sick or, whatever has popped up. Those sacrifices that I've made . . . I would have never done that if I wanted to be a professional. It's just not this semester; it's the whole time I've been getting my education. I started when I was 19 years old; I had two children. I had to make those sacrifices all along the way to

> get an education and if I didn't want to become professional, I would never have made the sacrifice. It's been very hard because I had to live on state aid to make up the difference of not having a job. And now, my husband is staying home, and in the Umo^{n}ho^n culture, men don't take care of their babies … their children. He has made the biggest sacrifice of all, which people here don't see the sacrifice that he has made for me, so that I can become a professional. It's very difficult because when I see professionalism, I see myself become . . . and living by those standards because otherwise, I will not . . . it's been very hard. So, I am learning how to do that still. And I still struggle with having to put things aside where if I were in a traditional setting, that I wouldn't have to do this.

Recapitulation

V. Identifying another Worldview?

Delberta's science bird and sound units emphasized knowledge about the natural world, social customs, language, heritage, and religion support the children's educational success. She identified that storytelling, song, and Umo^{n}ho^n language were successful strategies. I believe that I attempted to create the same with the pre-service teachers in the science methods course. Using storytelling was an essential strategy to support the pre-service teachers emerging professional knowledge landscape. After Delberta and the three other pre-service teachers' presentation at NIEA, in South Dakota, many Native American educators shared with them that, "storytelling to teach, what a good idea."

Delberta and I differed in how we developed relationships. I've watched Delberta build relationships with children in her classes and with elders as she explained the importance of relatives and those relationships. Building relationships comes from giving Native American children opportunities to identify: (a) Who are you? (b) Who are your relatives? (c) What is your heritage? Delberta has a solid grounding and understanding of the children, their relatives, and their heritage; she was able to "make that relationship with them." She can do this as an insider; as an outsider, I have limited knowledge.

For me, relationship building means to provide opportunities for each of us to be honest and to be vulnerable in proximity as we struggle together to construct new understandings about teaching. I make myself available to each student when they need help. I move into their space. I encourage them. I give empathetic eye contact. I help them to be successful. This is how I build relationships.

Delberta and I think, act, and communicate differently about making relationships. When thinking about teaching science in a culturally responsive way, this knowledge about relationship building might prove to be helpful.

VI. Rebuilding After the White Tornado—Sacredness of the Teacherage

Since the Native American teachers' insider-outsider worldview is different from the non-native teachers' because of their personal practical knowledge, then reservation schools need Native American teachers to develop indigenous pedagogy specifically designed from local indigenous professional knowledge landscapes. A non-native may live on a reservation and gain a "grounding in the heritage language and culture to a particular place"; however, from my observations of the non-native teachers and non-native administrators living on the Reservation, they are still "trying to make the Indians give up their life and live like white men—go to farming, work hard, and do as they did; and if the Indians had tried to make the whites live like them, the whites would have resisted, and it was the same way with many Indians," Big Eagle–Wamditanka.

Good intentions are not enough. Sleeter's (2000-2001) insider–outsider assumption, provides an even greater complexity given "the belief that a firm grounding in the [Umo^{n}ho^n] heritage language and culture indigenous to a particular place [Umo^{n}ho^n Reservation] is a fundamental prerequisite for the development of culturally-healthy students and communities associated with that place, and thus is an essential ingredient for identifying the appropriate qualities and practices associated with culturally-responsive educators, curriculum, and schools" (Alaska Standards for Culturally Responsive Schools, 1998, p. 2).

I spent a lot of time creating the Teacherage into a mock elementary classroom so that I could provide opportunities for each and every pre-service teacher to experience, apply, and understand how teaching strategies create successful learning experiences for the children. I slept in the resource room, but I tried to keep my personal materials to a minimum, because I had organized the room into a resource library for supplies, materials, references, and individual file systems for the pre-service teachers. I did this because I believe that creating and engaging and motivating a learning environment is how a teacher motivates each child's curiosity for inquiry. I wanted to model this strategy so pre-service teachers could experience what learning is like in an engaging environment where they can socially and individually build and add to their understanding.

However, the Teacherage was the place for the pre-service teachers to learn how to create a new identity. The Teacherage is a safe haven for the pre-service teachers to try on new different identities and transform themselves into professional teachers. The Teacherage became the transformational place where the pre-service teachers re-entered their culture as professional teachers with a new professional knowledge landscape and entered the culture of the Reservation school with their personal practical knowledge about Umo^{n}ho^{n} culture. These new identities emerge only through great struggle, sacrifice, and courage. Delberta needed to redefine her understanding of professional in terms of the university, the Reservation school, her family, and her husband to create a new identity.

My redesign of the Teacherage to create a motivating learning environment was successful for some like Delberta and did the exact opposite for others. For one pre-service teacher in particular; she was never able to drop the walls she put up against me because I was just another encroaching, white settler moving into the Reservation. I didn't understand the sacredness of the Teacherage. I assumed that the Teacherage was a university classroom, where I would also sleep, while I was teaching the methods courses and supervising the practicum and student teachers. I offended some pre-service teachers even before they entered my classroom, because they heard about this white woman who was moving things in the Teacherage, e.g., like a chair that a student sat in the corner of the room. This may seem trivial to some; however, for the Umo^{n}ho^{n}, after generations of displacement, disease, attacks, broken-treaties, Reservation land, and resource cessation by encroaching white settlers this was no trivial action.

Conclusion

Many funded projects, administrators, and teachers have come to the Reservation school, with good intentions to tell Umo^{n}ho^{n} people what and how to teach Umo^{n}ho^{n} children. Now, another well-intentioned, white teacher has come to the Reservation to make changes and has changed the Teacherage, a transformational place. Yet, do any of these well-meaning, white educators have enough of the external-insider " … firm grounding in the Umo^{n}ho^{n} heritage language and culture indigenous to the Umo^{n}ho^{n} Reservation that is a fundamental prerequisite for the development of culturally-healthy students and communities associated with that place, and thus is an essential ingredient for identifying the appropriate qualities and practices associated with culturally-responsive educators, curriculum, and schools" (Alaska Standards for Culturally Responsive Schools, 1998, p. 2)?

This is a very heavy burden for me; I am preparing to return this summer to teach science methods again to a new cohort of pre-service teachers on the Umo^{n}ho^{n} Reservation. I believe that the purpose of teacher education programs is about providing children opportunities to learn strategies to thrive and survive successfully in their future lives. Delberta's story emphasizes that, "in order to survive, Native Americans throughout history learned to live in harmony and to take care of the natural world; today, survival for the Native American child and the survival of the tribe is the key for educational success." "One of our elders and most recognized speakers once said, 'the prophecies say that the time will come when the grandchildren will speak to the whole world. The reason for the Freedom School is so the grandchildren have something to say'" (Sakokenionkwas, Porter, T.).

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DISCREPANT QUESTIONING AS A TOOL TO BUILD COMPLEX MENTAL MODELS OF RESPIRATION

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Research in science education shows that students often fail to retain knowledge gained in the classroom. There may be two reasons for this. First, many teaching methods do not allow students sufficient opportunity to process knowledge, to understand deeply enough to integrate new knowledge with old. Second, research shows that many students have misconceptions, ideas that they have gained through their own experience that are different from scientists, ideas. Misconceptions can prove to be quite resilient, and students often "bounce back" to their former ideas after a short while.

Discrepant questioning is a teaching technique that can help students "unlearn" misconceptions and process science ideas for deep understanding. Discrepant questioning is a technique in which teachers question students in a way that requires them to examine their ideas or models, without giving information prematurely to the student or passing judgement on the student's model. This strategy may also be called dissonance producing, because it prompts students to see the contradictions in their model, the ways in which it is unworkable. Evidence suggests that students in classrooms where discrepant question was a major part of the curriculum produced dynamic models of respiration, constructing complex concepts into an integrated whole.

According to Tweney (1987), all science involves an attempt to construct a testable mental model of some aspect of reality and involved in most kinds of problem solving tasks and in most kinds of inferential reasoning. "The self creates a new and different world - a cognitive

[1]construction- and the representations created become models and theories in science; as images are pictures of reality, the act of imagining is the manipulation of mental pictures as opposed to the manipulation of concrete objects."

Unfortunately, many students have difficulty building testable mental models and understanding concepts in science. It may be that some of this difficulty is due to students' inability to develop mental models, which requires integration of causal and dynamic knowledge with static knowledge (Gobert & Clement, 1994). While expert's knowledge is relational, held in complex conceptual models, making it easily stored, quickly retrieved, and successfully applied, students' knowledge is often rote, therefore easily forgotten and not readily transferable to similar situations (Glynn & Duit, 1995). Traditional education fails to make students aware of their own capacity for mental imagery and does not provide much opportunity to develop this inner resource (Greeson & Zigarmi, 1985). Even those teachers who realize that students need to actively construct conceptual models rather than memorizing lists of unrelated facts often are not sure how to facilitate constructive learning (Glynn & Duit, 1995).

It has long been a common learning strategy for students in biology to memorize long lists of words, categories, and definitions. Unfortunately, definitions have been shown to tend to freeze a mental model which may be appropriate when the goal is simple assimilation or rote memorization without change in the mental model. When the goal is the evolution of a mental model, the simple memorization of definitions may serve only to rigidify the process and thereby stifle further change (Tweney, 1987). According to Tweney, "Do we want to freeze so much conceptual material in the minds of our students? What happens to the capacity to modify one's mental models if we do? If we aren't showing them how science works, can we really expect them to become scientifically literate in the sense needed for today's world?" (Tweney, 1987).

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Several strategies have been suggested for encouraging the development of mental models of complex ideas (Glynn and Duit, 1991; Gobert & Clement, 1994). Short interviews, discussions, demonstrations of familiar phenomena, and discrepant events may activate existing mental models. Subsequent construction can then be supported by asking students to find relations, map concepts, and draw analogies. In addition, using think aloud strategies, asking the student to explain both right and wrong answers may be useful.

In order to support the construction of five concepts determined important in understanding respiration, the curriculum included a combination of strategies mentioned above. It was believed that this sequence would lead to dissonance, construction, criticism, revision, and questioning on the part of the students and ultimately to a complex mental model of respiration. In this pedagogy, it is the teacher's role to provide prompts, questions, and sources of dissonance to support this construction cycle in the student. One specific strategy employed in the current research is discrepant questioning. In this paper we will take a closer look at this one strategy. We recognize that this is just one of many strategies that work in union to promote the development of complex mental models, but we consider it to be a very important one.

Model Cycling

Discrepant questioning is a teaching technique that can help students "unlearn" misconceptions, make rational decisions about what they believe, and process science ideas for deep understanding. Discrepant questioning is a technique in which teachers question students in a way that requires them to examine their ideas or models, without giving information prematurely to the student or passing judgement on the student's model. This strategy may also be called dissonance producing, because it prompts students to see the contradictions in their model, the ways in which it is both workable and unworkable. Evidence has shown that students in classrooms where discrepant question was a major part of the curriculum produced dynamic models of respiration, constructing complex concepts into an integrated whole. To better understand the role of discrepant questions within the larger picture of mental model construction, Figure 1 provides an schematic of a typical cycle of mental model construction.

A typical cycle of mental model construction may occur in the following fashion: (1) a discrepant event, observation, discrepant question, teacher model, or discussion is introduced that (2) triggers dissatisfaction with a prior model. This may be in response to prior conceptions expressed by the students or a teacher recognized discrepancy in student models (M_1). Then, (3) through the use of other models, hands on activities, discrepant questioning, or analogy the student begins to build another model, M_{1a}; (4) once M_{1a} is developed, it is criticized and defended. (5) The model is applied to a new situation, and (6) the model is reevaluated in light of new information and understanding. In simple or shallow misconceptions, M_{1a} may become the final model consistent with the scientific model, and my be called the M_2. In more complex conceptions, however, this may only be a beginning step in a cycle which will repeat itself many times until the final model is reached. Following step (6), other discrepant events, observations, and analogies may be introduced to instigate another model cycle, with each cycle assisting the student in developing more and more sophisticated models. This becomes a rich cycle of concept development, criticism, and revision along with application to new situations.

A key element of this model cycling is that the student is not left with mere dissatisfaction with a prior model but in repeated cycles is simultaneously helped to criticize and construct new mental models. The major factor in this model is the constant reliance on the student's reactions, need for support, questioning, and reasoning that is going on within the steps of the cycle (Rea-Ramirez, 1998). To provide this support results of our research has suggested that the use of certain questioning strategies play an essential role.

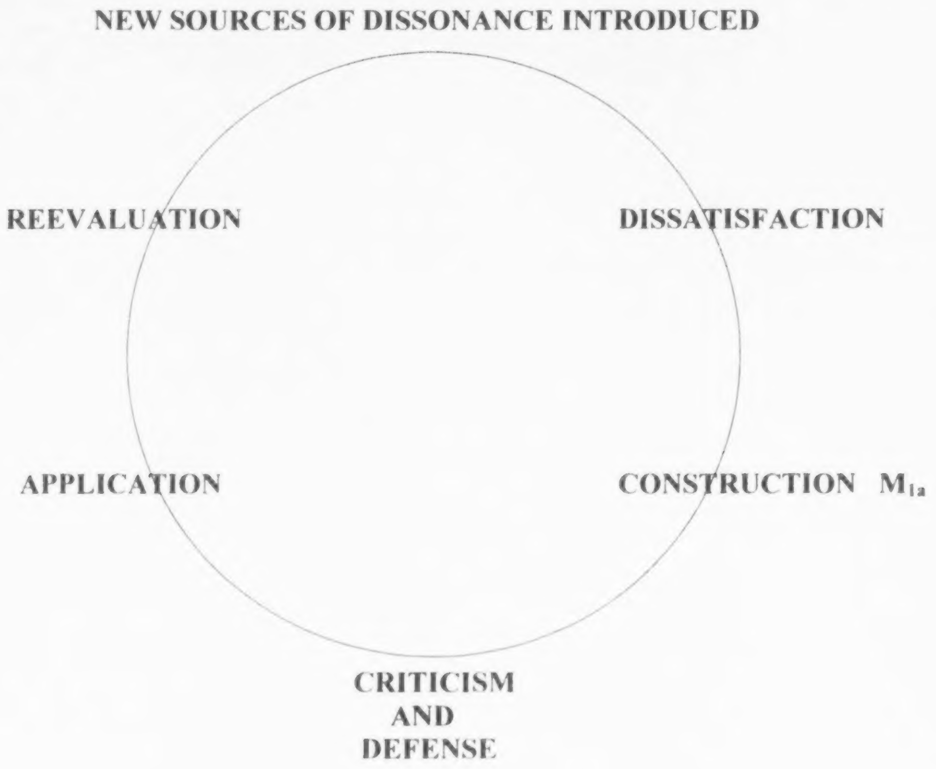
NEW SOURCES OF DISSONANCE INTRODUCED
REEVALUATION
DISSATISFACTION
APPLICATION
CONSTRUCTION M_{1a}
CRITICISM AND DEFENSE

Figure 1. Model cycling occurring in a spiral fashion. Over all, cycles are under the control of the teacher but affected by student's mental model construction cycles.

The introduction of dissonance plays a critical role in the modeling cycle. Where proponents of learning cycles recommend introducing a lesson with exploration, the modeling cycle relies heavily on sources of dissonance to initiate mental model construction within the student. Where others describe process skills and knowledge attainment, this model suggests that what might be most important is appreciation for the way students are developing understanding. Mostly, however, it suggests that it is the student who controls the learning and the teacher who helps facilitate that process, providing scaffolding and encouragement. It is the actual mental model construction that occurs within the mind of the student that is critical, not the lesson plan, or the curriculum guide, or covering the material. Students may actually vary in their reactions to dissonance and to cycle sequences. This suggests that numerous cycles may also be occurring within the larger modeling cycle that represents the cognitive construction process within the student. These repeated cycles might be thought of as a coiled spring laid out along the circle produced by one turn of the model cycle with each coil of the spring representing a small step in the model construction (Figure 2). What is occurs during each coil is what becomes primary in the student-teacher interaction. This is where discrepant questioning plays a major role in the criticism – construction cycle.

Discrepant questioning may take on several forms. Some questions are deep while others were shallow. Questions are viewed as shallow or deep depending on the amount of dissonance necessary to cause dissatisfaction with at model and promote model construction. Questions are used before, during, and after the model construction process. Before the model construction process, the teacher may use "open-ended questions" or "What if" questions to detect the students' initial understanding (M_1) of the Target Model. During the model construction process, the teacher may use several kinds of questions to help the students build a more sophisticated model (M_2) of the Target Model. The teacher uses Questions to direct the students' thinking in building and criticizing models when the students appeared to have had more preconceptions of the topic.

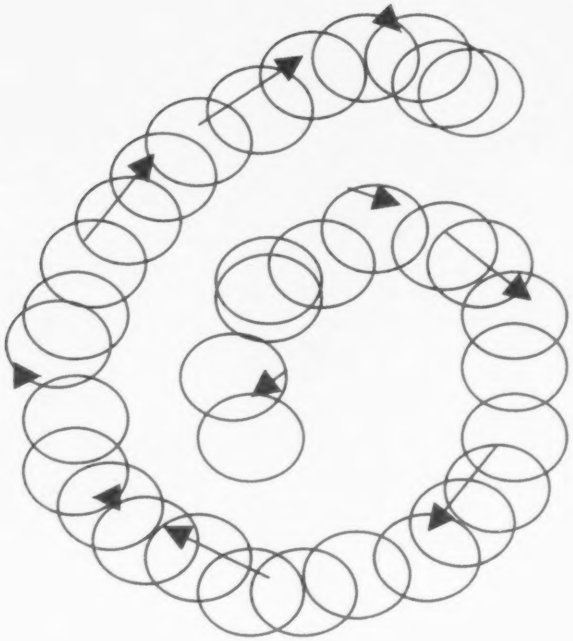

Figure 2. Coiled spring representation of student construction. While the teacher may have a broad cycle in mind, the teacher also recognized that the student is actually going through many multiple mini-cycles internally in order to reach a target concept. Each small circle in Figure 2 represents the one larger circle in Figure 1.

Kinds of Questions

Discrepant questions are used as both "dissonance-producing strategies" and as "supporting strategies." By using questions as "dissonance-producing strategies," the teacher introduces alternative ideas or counter arguments to promote dissatisfaction within the students' models. Among the Questions that act like "dissonance-producing strategies" are "hint questions," "recalling-information questions," and "student questions." By using questions as "supporting strategies," the teacher detects the effect of the alternative ideas or counter arguments in the students' models and keeps the model construction process going. Among the Questions that act like "supporting strategies" the teacher might use "information-seeking questions," "prediction questions," and "assessment questions." After completing the construction of the intermediate model (M_3), the teacher employs "adjustment questions" that act like a "supporting strategy." "Adjustment questions" help the students to compare their final models (M_3) with their initial (M_1) models. In this paper we will attempt to provide evidence of the different types of questions that we believe can be grouped under the heading "discrepant questioning".

How and When to use Discrepant Questioning

Knowing when and what questions to use to stimulate model construction is essential. To do this the teacher must have in mind not only the ultimate target model but also recognize what the current mental model is that the student holds. That is, the teacher sees the end but also the student's beginning, as indicated in Figure 3. Once the teacher can visualize the student model, he/she then constructs an intermediate target model as a "stepping stone" for the student on the journey toward the target. Using discrepant questioning, and other strategies, the teacher helps the student construct, criticize, and revise their model until it comes more closely to the intermediate model. The teacher then assesses the student's M_{1a} to see how closely it resembles the intermediate model envisioned by the teacher. If it is still not in the direction necessary to assist the student in building the ultimate target model, the teacher may have to use other analogies, discrepant questions, etc. to provide other opportunities for construction and dissatisfaction with the initial model.

This process occurs repeatedly with new intermediate models until the target is reached. An essential ingredient in the success of this model of pedagogy, is the teacher's willingness to take the time and effort to understand the student's model and to construct along with the student. That is, the teacher provides the students with successive counter-arguments and constraints that stimulate the students to review and modify their ideas (Nunez, et al 2002). The process is repeated over and over again with each individual concept involved in the topic of the lesson.

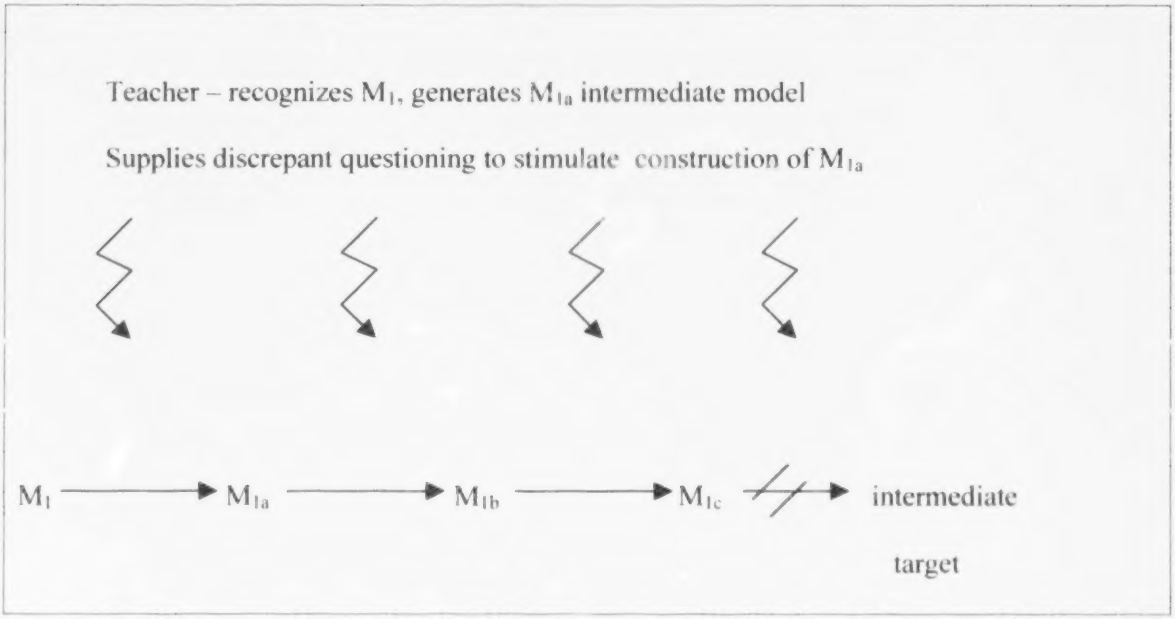
Teacher – recognizes M_1, generates M_{1a} intermediate model
Supplies discrepant questioning to stimulate construction of M_{1a}
M_1
M_{1a}
M_{1b}
M_{1c}
intermediate
target

Figure 3. Cycle of model construction based on teacher generated new intermediate models that are optimally planned to step students through a construction process to the target model. Introduction of discrepant questions, analogies, discrepant events, hands on activities help students construct each new intermediate model. Intermediate models are designed by the teacher based on students' initial models and reactions throughout the construction process. The number of steps to the target is determined by the difficulty of the concept and the strength of the prior model.

"What if" questions are employed throughout the proposed curriculum to help students in constructing new mental models. This is perhaps the broadest sense of questioning that can activate students' existing knowledge, relate this knowledge to experiences, and intrinsically motivate students (Rea-Ramirez, 1998). When "what if" questions are asked during and after a lesson they could encourage students to evaluate, revise, generalize, and apply their knowledge (Glynn & Duit, 1991). Examples of "what if" questions that might be used by the teacher in the study of respiration are:

1. "What would happen if the capillaries were located a long distance from the cells?"
2. "What if the cell needed energy, what would it need to get this energy?"
3. "What if I asked you to go run up and down the steps - what would you feel?"
4. "What if I could take a very thin section of the heart tissue - what would you see?"
5. "What if blood vessels ended when they got to your finger, as you have suggested. What would happen to the blood?

In each instance the students are encouraged to think about their prior models and experiences to suggest explanations, as well as to evaluate these models along with emerging models. Students are often asked to look back at prior drawings to make comparisons and suggest new models through the "what if " questions. The following question was used with all of the participants to encourage model development through mapping between an analogy and the cell: "Look back at your drawing of the cell as if it were a school. In that model you said there would be chaos if you only had one big room where all the classes and gym and band took place. What if you only had a big open space in the cell where everything took place?" In this instance, students are not only encouraged to compare prior models to a newly emerging model, but are asked to apply that model to suggest causal relationships.

Deep questioning encourages students to make inferences, think logically, and extend their thinking about mental models. Questions in this curriculum rarely ask for factual information in the form of simple recall or memorized facts but rather encourage students to think deeper, to apply what they are envisioning. Students are prompted to apply the models they constructed and then to criticize them through questions such as, "Would any cells need more energy in the form of ATP than other cells in the body? Tell me about that" and "What if you removed one lung, what might happen?" and "If blood is only pumped out to the body one way and goes into the tissues, where do we get more blood to keep pumping out?" In one instance, when students showed tubes sending inhaled air directly to the heart but drew lungs as separate organs unconnected to the inhaled air, the teacher questioned, "I wonder why we have lungs then? What might their purpose be?" After having students take a deep breath of air, the students say the lungs get bigger, which is incompatible with their model. "I wonder why they do that if the air just goes directly into the heart?" When another student suggested that air goes from the mouth through the esophagus to the stomach and diffuses out of the intestines just like the glucose, the question was posed, "I wonder though, if your stomach was holding all that air, where would the food go?" This stimulated a criticism and building response in the student which could be co-constructed with the teacher through a series of discrepant questioning. This is not to say that the student immediately gave up this model, but that he began to suggest other intermediate models finally coming up with two hypotheses that could be tested.

In attempting to apply a mental model to a new situation, it is necessary for students to look critically at their mental model to see where it may be supported and where it may still need revision. In trying to investigate students' understanding or construction of understanding about diffusion, deep questioning was used to induce students to generate models and then to predict behavior. "If I have a glass of water and I put a few drops of dye into it, what will happen?" (various answers about spreading out or just turning a color) "I wonder how that happens, what it would look like if you could look at the water and dye very close up?" Finally, deeper understanding and explanation was often encouraged by statements such as, "Tell me what you mean by ____________" or, "Tell me more about that" and, "I wonder what that looks like?" Simple statements such as these told the students the teacher was listening, interested, and encouraging the student to continue talking.

Some questions required that the student use logical reasoning to build on what they already know and to make new connections. Example of this question include, "How could you figure out what glucose was primarily made of if you looked at the by-products" or, referring back to student's analogy of the cell to the federal government, "If it is winter what would the government buildings need?" (Student states, energy). "Now can you relate this need to the cell? Where in the government model would you produce energy? And how about in the cell?" At other times questions encourage students to use previously constructed explanatory needs to make predictions. "If all the cells in the body need glucose and oxygen, how do you suppose it gets to the cells, where does it come from?" After students suggest a variety of models of the lungs including just tubes to balloons and they have constructed that model with sugar cubes, they are asked, "Can you think of any other way that we could arrange the cubes so there would be more surfaces for air to come out?" In this instance, a hands-on activity is used in combination with discrepant questioning to encourage construction of a model.

There are times, however, that for clarification or reiteration necessary to stress a point, shallow questioning is necessary. This is often the case when students express ideas and the teacher wants to be sure that she is clear about what the student means. In these instances, shallow questions might include, "Where is that on your model or drawing" and "What in the animation might indicate a new product was made?" At other times shallow questioning can be used as part of a scaffolding strategy. Students are asked to give small pieces of information back to the teacher who then helps the student to begin integrating these pieces into a larger picture. "How do animal cells get glucose?" "What is the heart's job?" "Is there anything in your model that acts like the nucleus?" "What kind of fuel might the cell use to produce energy?" These are all examples of shallow questioning that is intended to help build a larger concept, not to stimulate a deep explanation in itself. Often these questions trigger a connection within the student that then stimulates construction, speculation, and prediction.

Evidence of Discrepant Questions

Methodology

Evidence presented in this section is the result of an analysis of small group tutoring sessions on human respiration. Four two-hour classes were held with a group of four eighth-grade students. The group included two boys and two girls, and was ethnically diverse. Each session was audio- and videotaped. The instructor was the main researcher of the project. Subsequently, the curriculum has undergone extensive whole classroom trials in three schools over the past two years.

The students were instructed with a Standardized Teaching Sequence (STS) based on model construction and criticism theory that was developed by Rea-Ramirez (1998). The instruction was organized around five individual target models, which are related to the microscopic structure of the cell, internal structure of the cell, the digestive, the circulatory, and the respiratory systems.

Results

Evidence suggests that students had a marked increase in comprehension of human respiration. Quantitative analysis showed that the small group had an overall significant mean difference of over three standard deviations on the pre to post test. (see Nunez, 2002).

Questioning Strategies Used in Methodology

Discrepant questions have been divided into dissonance-producing strategies and supporting strategies. [Quotes in this section come from research conducted on small group interaction and reported in Nunez (2001).]

Dissonance-producing Strategies

Supporting evidence of Questions that acted like "dissonance-producing strategies" is provided below. These can be further divided into "hint questions," "information-recalling questions," and "students' questions."

Hint Questions:

The teacher used "hint questions" to suggest alternative ideas to the students to promote review and modification of their models. Two examples of "hint questions" were taken from the circulatory system. The teacher asked:

> Teacher: Ok, ok, so I'm still not clear. When the blood gets out to your toe what happens to it?
>
> S1: It backs up.
>
> S2: It is distributed to your foot and it goes back.
>
> S3: It's like a truck.
>
> Teacher: Tell me what that looks like. Let's draw a picture of when the blood reaches the big toe. [Drawing as she speaks] We go down to this toe level and I'm going to put a blood vessel here. Now, I'm going to call all of these things blood vessels, that is the name for all the different kinds…ok, is that all right with you? And I'm going to put one right here coming of down here. It's a pretty tiny one

> because remember how tiny the cells are? Now blood is coming through here. What happens when it gets to your toe?

In the first question, the teacher suggested that "something occurs when the blood arrives to the cell of the big toe." In the second question, the teacher enlarged her first question, and provided the students with a context such as a name for blood vessels and their relative size difference in respect to cells. The teacher also suggested that "something has to happen" in the toe when blood gets to it. By using the teacher's suggestions the students seemed to be able to examine and modify their ideas more concisely. The teacher also used other examples of "hint questions." Several of them were collected from the segment in which the teacher and the students Co-Constructed a more sophisticated model of the digestive system.

> Teacher: …beside just being a passage way, what may be happening in the intestine that might give you a hint about how glucose fits into your cells
>
> Teacher: How do you think it [glucose] goes, how do you think it goes from there to there [the intestine to the blood vessels]
>
> Teacher: I am going to draw a piece of intestine here, ok? [She draws] A piece that comes down like this and here is the food, food is all breaking up into little pieces, now we got some glucose. How does it [glucose] get from here out here [the intestine to the blood vessels]? Where does that blood vessels have to be? [She shows the drawing].
>
> Teacher: can your body break down everything that you eat? Have you ever eaten corn?

The teacher used "hint questions" when the students' prior knowledge could not get them any further within the model construction process. The alternative ideas suggested by the teacher might be considered to be "possible avenues" that can be explored by the students while building a more sophisticated model of the Target Model.

Information-Recalling Questions:

The teacher presented the students with "information-recalling questions" to remind them of the information that had been previously discussed. These types of questions seemed to have worked in two ways: 1) to contradict an idea given by a student; and 2) act as an analogy to help the students to generate new ideas.

The teacher asked "information-recalling questions" that caused contradiction when she and the students were Co-Constructing the circulatory system. One student said that blood was able to cross the blood vessel walls to provide glucose and oxygen to the cells of the big toe. The students seemed to have been confusing the relative size of cells and molecules. To solve the confusion, the teacher asked the students to recall information regarding the relative size difference among atoms, molecules, and cells that had been discussed in the previous lesson. The recalled information appeared to have contradicted the student's ideas. After the teacher asked the students to recall that information, a student was observed modifying her initial statement:

> Teacher: Ok, remember when we talked the other day about molecules and atoms and how tiny they were and they were much tinier than cells, right? [Drawing] And if this is a cell, here is the oxygen molecule, see how much difference that is?
>
> S3: Oh yeah.
>
> Teacher: Ok, we can't even see a molecule with the microscope. So when we were...when I have these here what I'm really talking about is like this and here is

> some oxygen on the blood cells [pointing at cells in the drawing]. Ok, so what do you think might happen?
>
> S3: Ah, hah…
>
> Teacher: So here is oxygen and glucose…[pointing the drawing]
>
> S3: I am thinking it goes through the walls. Because I mean, like, even if the blood that goes into the actual cell it has go through the walls to get into the cell, so I am saying, that it makes any difference like floating around inside the blood cells.

The recalled information appeared to have produced dissonance within the student's ideas concerning the model she was discussing with the teacher. The recalled information helped her to review and modify her initial ideas but not in the direction the teacher had expected. The student, instead of saying that the blood cells do not cross the blood vessel walls, said that, "blood has to go into the actual cell … like floating around inside the blood cells." The student appeared not to have had an understanding of a mechanism by which blood provides the cells with nutrients.

The teacher asked "information-recalling questions" that acted like analogies while the teacher and the students were Co-Constructing the respiratory system:

> Teacher: remember when we talked about the intestine and how close the blood vessels had to be to the intestine to pick up the stuff
>
> S4: very close
>
> Teacher: very close, what do you think is happening here?
>
> S4: it is seem that the blood cells are bumping into it, and then the oxygen has in there is… [He makes a noise with his mouth]

The teacher reminded the students of concepts that they had Co-Constructed while building models of the digestive, and the circulation system. The teacher asked the students to apply their prior knowledge to build a model of the respiratory system. The recalled information appeared to have acted as a conceptual core on which the teacher built the new idea.

Student Questions:

[The teacher used "student questions" to introduce alternative ideas to the discussion.] Some questions that the students asked were indirect questions, while others were direct questions. To detect the students' indirect questions, the teacher seemed to have been very aware of what the students were describing. When she detected an alternative idea, she initiated a discussion within the group about that idea. In the following piece of transcript, an example of the teacher and the students Co-Constructing a mechanism of blood transporting oxygen and glucose to the toe cells will be given:

> S4: They're [glucose and oxygen are] smaller than the blood cells, and they are carried by the cells. I do not know if these cells go into walls because…
>
> Teacher: Ok.
>
> S4: Like little things.
>
> Teacher: That's a really good question. Do the blood cells go through the walls?
>
> S2: They have to be able to.
>
> S1: There is a passageway
>
> Teacher: And what goes through the passageway, tell L. convince L if you think you're right. L if you think you're right then convince her [B].

A student proposed that glucose and oxygen are smaller than cells and that they sink through the blood vessels walls. However, he was not sure if the red blood cells were also able to sink through the walls. The teacher detected uncertainty in the student statement, and transformed the student's doubt into a question to be discussed within the group. In the transcript analyses, it was also detected that two students agreed with the student's alternative idea with the teacher's support, and she encouraged them to provide evidence for their arguments.

The students also asked spontaneous questions as well as bringing up questions when there was a discrepancy or difference between what was being debated within the group with what they knew about the topic. For example:

Circulatory System

S3: So have the people, like, donated blood?

Lower Digestive System

S2: if the food comes out of the veins, when you go to the bathroom what is that?

Upper Digestive System

S3: yeah, why do people choke?

Respiratory System

S1: I have a question

Teacher: uh huh

S1: if the air goes to the heart does it mean it goes to the lungs too

Teacher: hummmm

S1: or do you have oxygen in the heart? That is my question.

Teacher: that is a good question, what does the heart do?

S1: just circulates the air

Teacher: what do you think? Turn around and ask your teammates.

The teacher was never observed answering questions directly, but was observed tossing the questions back to the students. The "students' indirect questions," and the "students' spontaneous questions" were observed throughout the major segments of the teaching session.

Supporting Strategy

Below, evidence for the Questions that acted like "supporting strategies" is presented. They were "prediction questions" and "information-seeking questions."

Prediction Questions and Discrepant Questions

While the teacher and the students were Co-Constructing a more sophisticated model of the digestive system, the teacher promoted a discussion regarding the possible connection between the lungs and stomach. Two students believed that the lungs and stomach are connected, causing the presence of air in the stomach. A student supported her ideas by saying that when there is no air, stomach cramps are caused. The other student supported his ideas by saying that the stomach might collapse if there is no air inside of it. Meanwhile, a third student did not agree with the idea that the lungs and stomach were connected. She supported her ideas by saying that stomach cramps come from muscular contractions in the walls of the stomach.

To explore other student ideas regarding the topic, the teacher introduced a situation and then asked a "prediction question:"

Teacher: hum, what happens to your stomach when you drink a lot of like Pepsi or something that has a lot of bubbles in it.

S1: You burp, you have gas in your stomach

Teacher: humm, you get gas in your stomach

S3: it comes back up your esophagus

Teacher: ok

S1: and it is released

Teacher: so if you have air in your stomach, all the time what would that be like?

St1: you'd burp all the time

S3: you would be a walking burp

S4: you would be airy

The students agreed that if a person constantly had air in the stomach, that person would be burping all of the time. The "prediction question" seemed to have helped the teacher to detect the students' ideas in respect the topic.

The teacher detected that the students held two contradictory ideas. The first idea was that if a person has air in his/her stomach he/she might be burping all of the time. The second idea was if a person does not have air in the stomach he/she may have stomach cramps or the stomach's walls might collapse. To help the students to review and modify their ideas, the teacher asked the students a "discrepant question:"

> Teacher: so I wonder what do the rest of you think about that then there is natural air in your stomach?

The question generated a discussion among the students in respect to burping. The students realized that the source of a burp is the presence of air in the stomach. Therefore, it is not natural to have air in the stomach. As a consequence, the students realized that the lungs and stomach are not connected. The teacher seemed to have asked the "discrepant question" to help the students to reconcile the students' two opposite ideas.

Information-Detecting Questions

The teacher asked the students "information-detecting questions," such as "what do you think about that," to detect the impact of alternative ideas presented in the students' models. For example, while the students were discussing the location of blood vessels in respect to the intestine, a student suggested that blood vessels might be inside of the intestine. The teacher detected that the student may have been unsure of his suggestion, so she presented the student's idea to the group to be discussed:

Teacher: I wonder if there is blood in the intestine, what do you think about that?

S2: hum

S4: I am not saying that there is but (inaudible)

S1: Is there? I do not know

Teacher: Ok? What do you think?

St2: that would mean that blood would be coming out. I mean that every time that you go to the bathroom, you would bleed

(Group Laughs)

Because the teacher encouraged the students to present their ideas with her question "what do you think," one of them realized that the idea suggested by the other student was not worth further exploration. This might be seen as a point where the teacher led the students go to a blind alley to discourage continuing building incorrect ideas.

In addition to the "what do you think about that," the teacher frequently used other "detecting-information questions" styles such as,

Teacher: why might that be important?

Teacher: show us what you think about that.

Conclusion

In the research described, discrepant questions were used as "dissonance-producing tactics" and as "supporting tactics." By using questions as "dissonance-producing tactics," the teacher introduced alternative ideas or counter arguments to promote dissatisfaction within the students' models. Among the Questions that acted like "dissonance-producing tactics" the tutor used "hint questions," "discrepant questions," "recalling-information questions," and "student questions." By using questions as "supporting tactics," the teacher detected the effect of the alternative ideas or counter arguments in the students' models and kept the model construction process going. Among the Questions that acted like "supporting tactics" the tutor used "information-seeking questions," "prediction questions," and "assessment questions."

Evidence suggests that these students had a marked increase in comprehension of human respiration at the end of instruction. Quantitative analysis showed that the small group had an overall significant mean difference of over three standard deviations between the pre and post scores. Examination of drawings showed a progression from naïve and incomplete models to detailed models much closer to the scientific view (learning pathway). In addition, over the course of the instruction the students reached high level of interactions among themselves and with the instructor.

While the tutor guided the students in constructing intermediate models, she used several different "dissonance-producing tactics" to promote dissatisfaction within the students. The "dissonance-producing tactics" (Analogies, Questions, Daily Life Experiences, Pictures, Hands-on Activities, and others) were like a "tool box" to be used by the tutor. Because there were multiple strategies used, it cannot be stated that discrepant questioning by itself caused the results but rather worked together with other strategies for success. It is important to note that instead of selecting and using a "dissonance-producing tactic" at random, the tutor appeared to have chosen the most appropriate tactic to promote dissonance within the students.

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A COMPARISON OF TWO INNOVATIVE ALTERNATIVE PROGRAMS IN SCIENCE TEACHER PREPARATION

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Overview

In response to the critical need for licensed professionals prepared to teach science in middle and high schools, Pacific University has developed two innovative programs. The first, Alternative Pathways to Teaching (APT), is a program designed in partnership with local school districts as a second-career pathway to mathematics and science teaching. The second was developed in partnership with the Oregon Museum of Science and Industry (OMSI), the OMSI-Pacific University Science program (OPUS), and is intended to serve their current employees who work in informal science education settings. This presentation will describe the theoretical framework used for each design, the timelines and course sequences, the target audiences, and the successes and issues within each program to date.

Two Innovative Programs – APT and OPUS

Although the critical shortage of science teachers has led some institutions to ease their licensure requirements in order to produce more teachers (National Association of State Boards of Education [NASBE], 1998), Pacific University chose a different response. It was our conviction that we could recruit prospective science teachers if we targeted different pools of candidates from those where we draw for our traditional (MAT/5th Year) teacher preparation programs. One of the programs, APT, has targeted second-career or lateral-entry individuals – those who have been in the workforce for some time but are now seeking a career that will allow them "to make a difference". The innovation which successfully attracts these mature individuals is the combination of a strong support system with a paid internship to ease the financial transition to teaching.

The second program, OPUS, attracts individuals who are currently employed by the Oregon Museum of Science and Industry (OMSI) in their outdoor schools and other informal science education positions. Because they can maintain their full-time employment throughout the program, it is a financially viable option for young people who could not afford a traditional teacher education program.

Both programs evolved from design teams guided by a constructivist philosophy; these consisted of teacher education faculty and administrators for both programs. In addition, the APT design team included school district faculty, administrators, and teacher union representatives while the OPUS design team included science educators and administrators from OMSI. Early agreement was established on two significant goals: (1) The programs must maintain a pragmatic balance between theory and practice. To this end, the work of Charlotte Danielson was highly beneficial (Danielson, 1996); (2) we valued the emphasis on pedagogical content knowledge (PCK) as described by Shulman (1986, 1987) and supported in the *National Science Education Standards* (NRC, 1996): "Effective science teaching is more than knowing science content and some teaching strategies. Skilled teachers integrate their knowledge of science content, curriculum, learning, teaching, and students . . . . This special knowledge, called 'pedagogical content knowledge', distinguishes the science knowledge of teachers from that of scientists" (p. 62)

Courses are taught by professional educators with extensive middle/high school science teaching experience in addition to their backgrounds in research and instruction in institutions of higher education. Throughout the courses, integration of science content knowledge and pedagogical knowledge is placed in the context of student learning situations.

The design of the programs was also informed by the AETS Position Statement (Professional Knowledge Standards for Science Teacher Educators) (AETS, 1997), the National Science Teachers Association standards for pre-service teachers (NSTA, 1992), and the Oregon Science Education Council's Recommendations for the Preparation of Science Teachers (OSEC, 2001).

The reality of the science teacher shortages across the nation necessitates the development of creative and thoughtful solutions. Reviewing the programs of recent AETS annual conferences, it is clear that many states and institutions are struggling to develop high-quality programs to meet the shortages while balancing the tensions between competing goals: 1) providing the depth of instruction over time in order to prepare thoughtful, knowledgeable, and reflective science teachers, and 2) limiting the time, resources, and expense of preparation programs in order to produce licensed educators at a greater rate. Pacific University is pleased to share our approach through two unique programs designed to meet these challenges. For additional information regarding course offerings, schedules, or evaluation of the programs, please contact the author at wainwric@pacificu.edu.

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THE INFLUENCE OF A PHILOSOPHY OF SCIENCE COURSE ON PRESERVICE SECONDARY SCIENCE TEACHERS' VIEWS OF NATURE OF SCIENCE

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Introduction

During the past 85 years, almost all scientists, science educators, and science education organizations have agreed on the objective of helping students develop informed views of nature of science (NOS) (Abd-El-Khalick, Bell, & Lederman, 1998). Presently, despite their varying pedagogical or curricular emphases, agreement among the major reform efforts in science education (e.g., American Association for the Advancement of Science [AAAS], 1990; National Research Council [NRC], 1996) centers around the goal of enhancing students' views of NOS.

However, research has consistently shown that K-12 students have not attained the desired understandings of NOS (Duschl, 1990; Lederman, 1992). Similarly, science teachers were found to harbor several naïve views of NOS (e.g., Abd-El-Khalick et al., 1998; Billeh, & Hasan, 1975; Bloom, 1989; King, 1991). To mitigate this state of affairs, several attempts were undertaken to improve science teachers' NOS views (e.g., Akindehin, 1988; Billeh, & Hasan, 1975; Haukoos & Penick, 1983, 1985; Ogunniyi, 1983; Olstad, 1969). In a comprehensive review of these attempts, Abd-El-Khalick and Lederman (2000) concluded that these efforts were generally not successful in helping teachers develop understandings that would enable them to effectively teach about NOS. Nonetheless, they noted that an explicit reflective approach to enhancing teachers' conceptions (e.g., Abd-El-Khalick et al., 1998; Dickinson, Abd-El-Khalick, & Lederman, 1999; Shapiro, 1996) was relatively more effective than an implicit approach that utilized hands-on or inquiry science activities lacking explicit references to NOS (e.g., Barufaldi, Bethel, & Lamb, 1977; Haukoos & Penick, 1983, 1985; Riley, 1979).

Yet, in our own research, we found that even though an explicit reflective approach undertaken within science methods courses was successful in positively influencing science teachers' views of NOS, the translation of these views into instructional practices was, at best, limited and mediated by several variables (Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Among these factors was science teachers' *depth* of understanding of the target NOS aspects. Abd-El-Khalick and Lederman (2000) argued that to be able to effectively teach about NOS, science teachers need to have more than a basic knowledge and understanding of some NOS aspects. Teachers need to know a range of related examples, demonstrations, and historical episodes. They should be able to comfortably discourse about these NOS aspects, contextualize their NOS teaching with some examples or "stories" from history of science, and design science-based activities to render the target NOS aspects accessible and understandable to K-12 students. In other words, science teachers need to have some level of NOS pedagogical content knowledge (NOS PCK).

There is a limit to what can be done within the context of science teacher education programs given their already extensive and overly long agendas. Thus, the efforts undertaken within these programs to help prospective teachers develop deep understandings of NOS need to be augmented with relevant coursework in other disciplinary departments. Intuitively, coursework in philosophy and history of science serve as primary candidates. Indeed, during the past 40 years, science educators have repeatedly argued that philosophy of science (POS) can play a significant role in helping learners develop more informed conceptions of NOS (see Matthews, 1994; O'Brien & Korth, 1991; Robinson, 1969; Scheffler, 1973). However, despite the longevity of these arguments, and to the best of the researcher's knowledge, there are no systematic empirical studies in the science education literature that examined the influence of

POS courses on science teachers' NOS views or related instructional practices.

NOS

Philosophers, historians, and sociologists of science, and science educators are quick to disagree on a specific definition for NOS. The use of the phrase "NOS" throughout this proposal instead of the more stylistically appropriate "the NOS," is intended to reflect the author's lack of belief in the existence of a singular NOS or general agreement on what the phrase specifically means. This lack of agreement should not be disconcerting or surprising given the multifaceted, complex, and dynamic nature of the scientific enterprise. It is our view, nonetheless, that there is an acceptable level of generality regarding NOS that is accessible to K-12 students and at which virtually no disagreement exists among experts (Lederman & Abd-El-Khalick, 1998).

Some of the aspects of NOS that fall under this level of generality are that scientific knowledge is: tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), theory-laden, partly the product of human inference, imagination, and creativity (involves the invention of explanations), and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationship between scientific theories and laws. These NOS aspects, which were adopted and emphasized in this study, have been emphasized in recent science education reform documents (e.g., AAAS, 1990; NRC, 1996).

Method

The present study was exploratory and interpretive in nature. The study aimed to assess the influence of a POS course on preservice secondary science teachers' (a) views of NOS, (b) perceptions of teaching about NOS in their future classrooms, and (c) instructional planning related to NOS. Data collection was continuous and spanned the duration of the study. Numerous data sources were used to answer the questions of interest. Figure 1 presents an overview of the study's participant students and courses, timeline, procedure, instruments, and data sources.

Participants

Participants were all 32 preservice secondary science teachers, 20 female (62%) and 12 male (38%), enrolled in the first two of a four-semester science methods course sequence. This course sequence is a part of a two-year combined undergraduate-graduate teacher preparation program at a large Midwestern University. Participants' ages ranged from 19 to 25 years ($\underline{M}$ = 20.9 years, $\underline{SD}$ = 1.3 years). Of the participants 3 (9%) were juniors, 20 (62%) were seniors, and 9 (28%) were graduates. With one exception, all graduate students had just started their graduate studies and, thus, were not substantially different in their ages and science content backgrounds from the greater majority of the undergraduate participants.

The study spanned two semesters. During Fall term, all participants were enrolled in the first science methods course (Science Methods I). During Spring term, all participants were enrolled in the second science methods course (Science Methods II). Additionally, four of the graduate participants, three female and one male ($\underline{M}$ = 22 years) were enrolled in a graduate survey course of POS (see Figure 1).

Context and Intervention

The intervention was undertaken in the context of the aforementioned three courses, which are taught by the author. Science Methods I aims to introduce students to teaching science in a diverse society. The course explores the goals for science education past and present, contemporary conceptions of NOS, the diversity of secondary school students, "science literacy for all" in the context of a diverse society, and current directions and trends in science education. Over the course of 12 instructional hours toward the beginning of this course, a set of 15 generic activities and three readings were used to provide participants with opportunities to examine and reflect on their own views of NOS, and to explicitly introduce them to the target aspects of NOS. Detailed descriptions of these activities can be found elsewhere (Lederman & Abd-El-Khalick, 1998). A whole-class discussion followed each activity and involved students in active discourse concerning the presented NOS aspects.

Additionally, in Science Methods I, participants wrote two NOS-specific reflection papers in response to two readings. The first paper, which was written toward the beginning of the explicit reflective NOS instruction sessions (see Figure 1), was in reaction to the McComas (1996) reading. Students were asked to discuss the NOS ideas presented in the reading and compare those ideas with their own NOS views. This paper was intended to get participants' to clarify and confront their own views of NOS. For the second reflection paper, participants were asked to read the prologue for Penrose's (1994) *Shadows of the Mind: A Search for the Missing Science of Consciousness*, and answer the following questions: "Do the ideas in this reading fit our discussions of some aspects of NOS? If yes, how? If no, why?" This short reading is a dialogue between young Jessica and her father. The father, a scientist, goes into a cave to collect some plant specimens and Jessica goes along. While inside, Jessica wonders what would happen if she, her father, and others got trapped inside the cave. Eventually, Jessica comes to ask, "How could I know what the real world outside was like? Could I know that there are trees in it, and birds, and rabbits and other things?" (Penrose, 1994, p. 2). The ensuing conversation focuses on how we "know" and how "valid" our knowledge is, as Jessica's father tries to explain to her how much they could learn about the outside world just by observing whatever shadows that might form on their cave walls. This second reaction paper was written following the conclusion of NOS instruction and was meant to provide students with an opportunity to reflect on their newly acquired NOS understandings (if any) and apply them in a novel context.

Science Methods II engages participants in a set of extended inquiry activities and other science teaching modalities for the purpose of providing them with learning experiences that are commensurate with ones that these preservice teachers are expected to foster in their own future classrooms. Activities are followed with structured discussions aimed at getting participants to reflect on the sort of learning experiences they have engaged, how these experiences differ from the traditional science teaching that many of these participants have experienced in their own science learning careers, and articulate the benefits and burdens of these espoused teaching approaches. The course also aims to help prospective teachers acquire practical skills in (a) planning science lessons that are consistent with current trends in science education, (b) utilizing a variety of media and resources for teaching science, and (c) applying various approaches to teaching science in secondary classrooms. In this course, participants prepared four detailed lesson plans that utilized a variety of instructional approaches, but that addressed topics and objectives of the students own choosing. Participants used their fourth lesson plan to guide their 30-minute peer teaching lessons toward the conclusion of the course. Following the completion of the fourth lesson plan, students wrote a reflection paper in which they discussed the impact that the discussed ideas about NOS in the two methods courses might have on their future teaching practices.

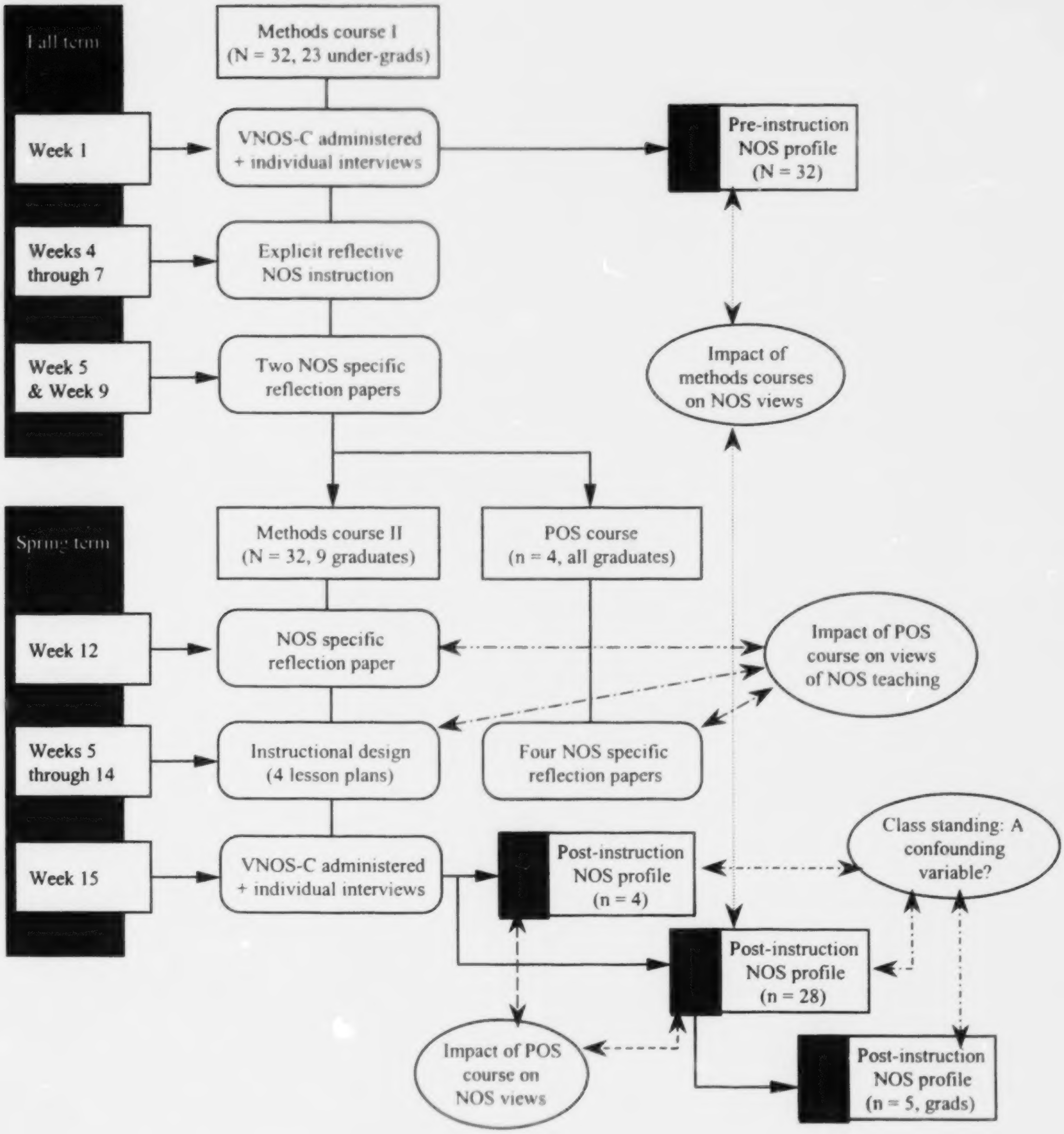
Fall term
Methods course I (N = 32, 23 under-grads)
Week 1
VNOS-C administered + individual interviews
Pre-instruction NOS profile (N = 32)
Weeks 4 through 7
Explicit reflective NOS instruction
Week 5 & Week 9
Two NOS specific reflection papers
Impact of methods courses on NOS views
Spring term
Methods course II (N = 32, 9 graduates)
POS course (n = 4, all graduates)
Week 12
NOS specific reflection paper
Impact of POS course on views of NOS teaching
Weeks 5 through 14
Instructional design (4 lesson plans)
Four NOS specific reflection papers
Week 15
VNOS-C administered + individual interviews
Post-instruction NOS profile (n = 4)
Class standing: A confounding variable?
Post-instruction NOS profile (n = 28)
Impact of POS course on NOS views
Post-instruction NOS profile (n = 5, grads)

Figure 1. An overview of the study's participant students and courses, timeline, instruments, and data sources.

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The POS course surveys issues that are central to science education through an exploration of the original works of twentieth century philosophers of science who were most influential in shaping thinking about science in the science education community. Relevant readings from science and history of science are also explored. Table 1 presents an overview of the topics addressed in the course along with some illustrative readings. The course aims to help students develop informed and critical views of NOS and its implications for science teaching and learning. To help students achieve these latter goals, they were required to write a total of four extended reflection papers in which they discussed the major ideas discussed in a set of sessions, compared these ideas about science with their own views, assessed any changes in their own NOS views, and discussed the ways in which, if any, the presented ideas were related to teaching pre-college science.

The experiences detailed above were the only explicit encounters that participants had with NOS during Fall and Spring terms. Participants were not enrolled in any other directly relevant courses (e.g., history, philosophy, or sociology of science courses). So, for the purpose of this study, participants could be situated in two groups: The "Methods" group, which comprised participants enrolled in the two methods courses, and the "POS" group, which comprised participants enrolled in the methods and POS courses. This grouping allowed assessing the impact of the POS course on participants' NOS views and perceptions of teaching about NOS (see Figure 1).

Procedure

The *Views of Nature of Science Questionnaire–Form C* (VNOS–C) (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001) was used to assess participants' views of the target NOS

Table 1

Overview of the Topics Addressed in the POS Course

Topic(s)	Illustrative readings
Induction and its failings, Bayesianism, Popper's falsificationism and its failings	Selections from Russell (1959), Harre' (1983), O'Hear (1989), and Popper (1992)
The Duhem-Quine thesis and underdetermination	Duhem (1998), Quine (1998) Case study: The dinosaur extinction controversy (Alvarez & Azaro, 1990; Courtillot, 1990; Glen, 1990, 1994)
Observation, theory, and incommensurability Kuhn on normal science, revolutions, resolutions, and progress	Kuhn (1996, 1998) Case study: The Copernican revolution (Kuhn, 1985)
Kuhn and his critics	Feyerabend (1993), Popper (1993), Watkins (1993) Case study: N-rays (Nye, 1980)
Sophisticated falsificationism	Lakatos (1993)
Empiricism and realism	Maxwell (1998), Toulmin (1998), Musgrave (1998), van Fraassen (1998) Case study: Competition in community ecology (Lewin, 1983; Roughgarden, 1983; Simberloff, 1983; Sloep, 1993)
Science and Pseudoscience	Feyerabend (1998), Lakatos (1998), Laudan (1998), Popper (1998), Ruse (1998a, b), Thagard (1998)
Science as social knowledge	Selection from Bloor (1976) and Longino (1990) Case studies: Selections for Collins and Pinch (1993)
Feminist approaches to science	Giere (1998), Keller (1997) Case study: Hominid evolution (Haraway, 1978, Hrdy, 1986; Lovejoy, 1981)

aspects at the beginning of Fall term and end of Spring term. Given the study's concern with the meanings that participants ascribed to the emphasized NOS aspects, it was imperative to avoid misinterpreting participants' responses to the *VNOS–C*. As such, individual semi-structured interviews were used to establish the validity of the questionnaire by insuring that the researcher's interpretations of participants' written responses were congruent with those elucidated by participants during the interviews. Eight randomly selected participants (25%) were interviewed: Four following the first administration of the *VNOS –C* and four following the second administration of the instrument. This latter procedure was undertaken to avoid the introduction of the pre-instruction interview, which could have served as a treatment, as a confounding variable that could influence participants' responses during post-instruction interviews. This approach allowed the use of post-instruction interview data both to establish the validity of the questionnaire and facilitate the interpretation of changes in participants' views.

During the interviews, which were conducted by the author, participants were provided with their pre- or post-instruction questionnaires and asked to explain and justify their responses. Follow-up questions were used to clarify participants' responses and further probe their lines of thinking. All interviews, which typically lasted about 45 minutes, were audio-taped and transcribed for analysis.

Additionally, participants' NOS-specific reflection papers from all three courses, and their lesson plans from the Spring science methods course were collated for analysis. The reader is reminded that while the reaction papers included explicit cues for participants to discuss issues related to the nature of the scientific endeavor and teaching about NOS, participants were not given any cues whatsoever for choosing topics or objectives for their lesson plans.

Data Analysis

The author analyzed the data. Another science educator conducted a blind round of analysis. The two analyses were compared and differences were resolved by consensus. This procedure was undertaken to insure the validity of the analysis given that the author was the instructor of the participant courses and could have perceived the data as partially evaluative.

Data analysis featured three phases. During the first phase, the collected lesson plans were searched for evidence to assess whether the participants planned to teach about NOS. The analysis focused on documenting explicit planned instances, including instructional objectives that were coupled with activities and/or discussions that overtly addressed one or more of the target NOS aspects. Isolated statements or references related to NOS that were inserted into an instructional sequence or glossed over during a planned discussion were not considered explicit instances of planning to teach about NOS. Moreover, activities that were consistent with a particular view of science, but did not explicitly focus students' attention on a target NOS aspect were also not considered explicit planned instances. For example, students' performance of a laboratory investigation was not considered an explicit instance of teaching about NOS, unless participants included planned questions aimed at engaging their students in a relevant discussion that emphasized certain NOS aspects.

During the second phase of data analysis, participants' NOS-specific reflection papers were examined to gauge changes in participants' NOS views and assess their views regarding teaching about NOS in their future classrooms. The reader is reminded that the Methods group participants addressed this question in a reflection paper written toward the end of the Science Methods II course, while the POS group grappled with the same question throughout the POS course (see Figure 1).

Participants' *VNOS–C* questionnaire responses were examined during the third phase of data analysis. Analysis started with the pre-instruction questionnaires of the four randomly interviewed participants, which were used to generate a profile of their NOS views. The corresponding interview transcripts were then used to generate another profile of these participants' views. The independently generated profiles were compared and indicated that the researcher's interpretations of participants' NOS views as elucidated in the *VNOS–C* were congruent to those expressed by participants during individual interviews. This procedure was repeated with the post-instruction questionnaires and interview transcripts of the other four interviewees resulting in similar congruency. Next, all questionnaires were analyzed to generate pre- and post-instruction profiles of participants' views. Each questionnaire was used to generate a summary of a participant's NOS views. These summaries were then searched for patterns or categories, which were checked against confirmatory or otherwise contradictory evidence in the data and were modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily reduce and organize the data for a certain group of participants.

It should be noted that a decision was made to analyze participants' lesson plans prior to examining their NOS-specific reflection papers and *VNOS–C* questionnaires in order to avoid biasing the results of analyzing these instructional plans. Examining participants' NOS views and their statements regarding teaching about NOS in their future classrooms prior to analyzing their lesson plans could have created a mindset that might have lead the researchers to read into some participants' instructional plans and inaccurately categorize some planned sequences as explicit instances of planning to teach about NOS. As such, examining participants' reflection papers and *VNOS–C* questionnaires was deferred to the latter phases of the analysis.

To answer the questions that guided the present investigation, the results of each of the above analyses (i.e., lesson plans, refection papers, and *VNOS–C* questionnaires) were clustered by group of interest (i.e., the Methods group *versus* the POS group). Next, the group results were compared and contrasted to assess the impact of the POS course on participants' NOS views, perceptions of teaching about NOS in their future classrooms, and instructional planning related to NOS. Finally, it should be noted that the four participants in the POS group (i.e., students enrolled in the Methods and POS courses) were graduate students, while the greater majority of the Methods group participants (i.e., students enrolled in the Methods courses only) were undergraduates. To assess the possibility of class standing (graduate *versus* undergraduate) being a confounding variable in the present study, the aforementioned results were also clustered for the five graduate students in the Methods group and compared with the results for students in the POS group (see Figure 1).

Results

In the following sections, the letters "M" and "P" followed by a numeric are used to refer to individual participants in the Methods and POS groups respectively. Moreover, it should be noted that comparisons between the Methods group participants less the graduate students, the graduate students enrolled in the methods courses only, and the POS group allowed ruling class standing (i.e., undergraduate vs. graduate) as a confounding variable in the present study. The NOS views, views of teaching about NOS, and instructional planning related to NOS of graduate students in the Methods group were not systematically or substantially different from those of the undergraduate students.

Participants' Views of NOS

The NOS views of participants in the Methods and POS groups did not differ in any respect at the outset of the study. A majority of participants held naïve views of several of the target NOS aspects. Table 2 presents a summary of the pre-instruction NOS views of the Methods group participants, which is illustrative of the views of all participants. This summary appears in the second and third columns of Table 2. It should be noted that while column 2 reports the percentage of participants with informed views of the specified NOS aspect, column 3 presents an illustrative quote of participants' naïve views of this aspect.

Consistent with prior research findings (see Abd-El-Khalick & Lederman, 2000), a large majority of participant preservice teachers (90%) ascribed to a hierarchical view of the relationship between scientific theories and laws whereby theories become laws when "proven true." Also, as evident in Table 2 (columns 2 and 3), an alarming majority of participants (75%) seemed to believe that scientific knowledge is not tentative. Some of these participants articulated this view explicitly, while others conveyed it in their responses to various *VNOS–C* items. For instance, while almost all participants indicated that scientific theories do change with the advent of new evidence and the development of better technologies, a large majority believed that scientific laws are "facts" and not amenable to change because they are "proven to be correct." This latter view coupled with participants' belief in a hierarchical relationship between theories and laws, indicates that their comments regarding theory change were not associated with a tentative view of science. Rather, these comments reflected a naïve view of scientific theories as an intermediate step in the generation of "true" scientific knowledge (i.e., laws and facts). Indeed, about 70% of participants did not demonstrate informed views of the well-substantiated nature of scientific theories, their explanatory and predictive functions, and their crucial role as frameworks for guiding research. Instead, many participants ascribed to the term "scientific theory" meanings associated with the vernacular sense of the word theory as "someone's guess of what is going on."

Similarly, only about 30% of participants articulated informed views of the inferential, and creative and imaginative NOS. For instance, many participants noted that scientists were "certain" about atomic structure because "high powered microscopes" were used to discern this structure. Scientific models or representations of the atom were, as such, thought of as depictions of the way an atom "really" is. Participants failed to distinguish between scientific claims and the evidence supporting such claims. This conflation, according to which 'knowing is seeing,' transferred into participants' (uninformed) discussions of theories whereby many indicated that scientific theories could not be tested because, for instance, "no one was around when the dinosaurs became extinct . . . so, we will never know which extinction theory is true" (M12). Additionally, even though many participants noted that scientists use creativity and imagination in their work, only a handful (28.6%) articulated the view that such human attributes are integral to the creation of scientific models, theories, and explanations. Participants mostly used the term "creativity in science" to refer to scientists' resourcefulness in designing experiments and collecting data or their ability to make science interesting and accessible to the public.

A small minority of participants (17.9%) seemed to appreciate the theory-laden nature of observations and investigations. For instance, the majority dismissed the dinosaur extinction controversy on the scarcity of the evidence, with the implication that "when enough data is found, one hypothesis will become true and the other will be thrown out" (M 21). These participants did not demonstrate an understanding of the role of prior knowledge, assumptions, theoretical commitments, and guiding frameworks in influencing scientists' interpretation of,

Table 2

A Summary of the Methods Group Participants' Pre- and Post-instruction NOS Views (n = 28)

	Pre-instruction		Post-instruction	
NOS aspect	% Informed	Illustrative quote of naïve views	% informed	Illustrative quote of informed views
Tentative	25.0	Science is different from other disciplines of inquiry because there is an absolute truth and a right answer in science. (M 22)	50.0	Also, scientific theories and laws are similar in that they can also change. All scientific knowledge can change in the future, since we cannot be certain in science. (M 14)
Empirical	10.7	It is hard for me to think of the difference. I think science differs from religion because science can bring insight into questions like how something works, or what something is, but not why it exists. (M 11) Science is different from philosophy and religion in that it is about the facts as we observe them and not about opinions and interpretations. (M9)	60.7	Science is a way of thinking about the world. It is also a body of knowledge. It is different from other methods of inquiry because it is ultimately accountable to observations of nature. Sometimes observation can lead to different interpretations of the same natural phenomenon, but those different interpretations are subject to peer review and are eventually compared to the recorded observations. (M1)
Inferential (theoretical entities)	28.6	In this day and age of such advanced technology scientists are almost certain about the structure of the atom . . . They used strong microscopes such as electron microscope to clarify the structure. (M 27)	71.4	I believe this structure [of the atom] is a model. We can not see it. So, scientists had to do a lot of experiments and gather indirect evidence to come to this model which I think will be modified with new experiments and technologies as they become available. (M 4)
Creative and Imaginative	28.6	Scientists for the most part use scientific methods, logic and reasoning . . . Scientists need to use creativity because people are not interested in scientific findings, and a way is needed to make it appealing and meaningful. (M 24)	60.7	The most creativity and imagination is used when they [scientists] apply the data they found in their experiments to attempt to formulate theories explaining what they found. (M 17)
Theory-laden	17.9	Scientists reach different conclusions because of the enormous time that has passed since the dinosaurs extinction and no one was there to start with . . . So, they choose the piece of evidence that supports their own hypothesis. (M 8)	35.7	This is because of interpretation. The evidence can support one hypothesis or the other and this is related to the theory that the scientist is using and how he is approaching the puzzle of what killed all the dinosaurs. (M 2)

Table 2 (continued)

	Pre-instruction		Post-instruction	
NOS aspect	% Informed	Illustrative quote of naïve views	% informed	Illustrative quote of informed views
Social and cultural	39.3	Ultimately, science is universal and scientific knowledge is the same everywhere, it touches every person in every culture. (M 12)	53.6	The direction of scientific study and funding is affected by cultural values . . . But more than that science itself is infused with cultural values. Scientists are influenced by the culture in which they live . . . Even though Copernicus had concrete scientific data and observations that the Earth was revolving around the sun, the rest of Europe did not waiver from its heliocentric view, since it was imbedded in the religious structure of the time . . . popular culture and beliefs did not allow new, revolutionary scientific ideas to take hold at first since it went against the culture. (M 17)
Theories *vs.* laws	10.7	A scientific law is a theory that has been tested and proven true to be accepted as a law. (M 6)	50.0	A scientific law describes how some aspect of the world behaves. For example, Newton's laws of motion describe how objects move. They do not say why something moves, they just predict how something moves. A theory, like evolution, is an explanation of the natural world, and explains a phenomenon. (M 26)
Nature and function of theories	28.6	We learn about theories even though they change because it would be better to learn something like how the dinosaurs became extinct than not to study the subject at all. (M 10) A scientific theory is just an educated guess. It has not been proven completely. (M 10) An example of a scientific theory is the Big Bang theory, which can never actually be tested. (M 12)	64.5	Theories help us explain the world around us and how it works. By studying theories and testing them we can reject them or come up with better theories and knowledge. Theories kind of guide the work of scientists because they need to know what they are looking for in the first place. (M 1) Even though a theory can change in the future it does not mean that it is not supported by evidence. On the contrary, a theory is well supported by evidence and connects a lot of observations. This is done by comparing the consequences of the theory with observations. (M 9)

evidence. Moreover participants' discussions of the empirical NOS were largely naïve. Participants seemed to believe that science was solely about the "facts" and dismissed the role that a host of other personal and social factors play in the generation of scientific knowledge. Yet, when distinguishing between science and other disciplines of inquiry, such as religion and philosophy, many participants failed to refer to the empirical NOS as a major distinguishing attribute. Rather, many participants noted that science was different because it involved physical evidence rather than opinion, or because it offered a way to reach "certain knowledge rather than speculation." Finally, 40% of the participants discerned a role for social and cultural factors in the scientific enterprise. However, participants' comments were mostly related to the role of social values and concerns in prioritizing funding for scientific research. Only two students believed that science itself was an enterprise embedded in a larger social and cultural milieu that impacted the very nature of the science that is done and the acceptance of scientific claims.

At the conclusion of the study, several desired changes were evident in the Methods group participants' NOS views. As evident in Table 2 (columns 4 and 5), these changes were mostly substantial and evident in the case of all target NOS aspects. Some changes, however, were less pronounced than others. In particular, little change was evident in participants' views of the tentative and theory-laden NOS, and the social and cultural embeddedness of science. By comparison, changes were pronounced regarding the inferential nature of scientific entities, the distinction and relationship between theories and laws, and the empirical NOS. Yet, much remains to be desired. A substantial percentage of the Methods group participants (ranging from 30 to 50%) still subscribed to naïve views of one of the target NOS aspects or another. Furthermore, only a handful of these participants demonstrated informed views that fit within a coherent and overarching framework for thinking about science. Inconsistencies and compartmentalization were evident in the views of many participants. For instance, it was not unusual for some participants to note that scientists use creativity in developing scientific knowledge and then ascertain that science is distinguished by a prescriptive universal "Scientific Method" that guarantees valid knowledge. Similarly, some participants still indicated that scientific knowledge is tentative and subject to change only to indicate later in their questionnaires that laws are different from theories because they are proven "true." Finally, the NOS views of a significant portion of the Methods group participants were not supported with examples from the history or practice of science, or were otherwise supported with inadequate examples. For instance, the change from a "flat to a round conception" of the Earth was the most commonly cited example of theory change.

By comparison, the post-instruction questionnaires of all four POS group participants indicated that they have internalized informed views of almost all target NOS aspects. Table 3 presents illustrative quotes of these participants' NOS views. Moreover, in contrast to the Methods group participants, the POS group participants' NOS views were (a) more articulate and indicative of deeper understandings of the issues involved, (b) supported with adequate examples from the history and practice of science (these examples included ones not discussed in the POS course), and (c) more consistent across the *VNOS–C* items and reflective of more coherent overarching frameworks for thinking about the scientific enterprise and the generation of scientific knowledge.

Perceptions of Teaching about NOS

In their second NOS-specific reflection paper assigned during Fall term, almost all participants admitted to having ascribed to several of the naïve NOS ideas that were addressed during Science Methods I:

> These misconceptions about science are something that I certainly believed at some point as a result of how science is taught. I have memorized the steps of the scientific methods on several occasions and I was taught that theories become laws when they are proven to be correct. (M 3, reflection paper)

However, the reactions of participants to the implications of their newly acquired understandings about NOS were all but consistent. About one third of participants (34.4%) noted that they need to address NOS in their own teaching:

> As a future science teacher, I must change these misconceptions in students' minds. My students need to understand that science is constantly changing; that it is not a mechanical process for answers; that creativity is often involved; that science is actually not dull! (M 23, reflection paper).

These participants believed that by addressing NOS in their teaching, they will end up encouraging more students to "go into science":

> Students should learn the real nature, usefulness, and beauty of science. As a teacher, I intend to set up labs so that creativity is encouraged and practiced . . . I will also communicate what science can and cannot achieve . . . In the long run, I think this will encourage more students to choose science as a career path. (M 11, reflection paper)

This latter view, nonetheless, was not shared by a majority of participants. About one third of participants (34.4%) expressed hesitance about presenting science to their students as a "chaotic process of discovery that follows no scientific method and that is conducted by creative people" (M 22, reflection paper). These participants were concerned that their authority as classroom teachers would be compromised if they were to present science as a less-than-certain endeavor:

Table 3

A Summary of the POS Group Participants' Post-instruction NOS Views (n = 4)

NOS aspect	Illustrative quote of naïve views
Tentative	Theories absolutely change over time! Theories change because science and all scientific knowledge is never certain, "conclusions" are only tentative. They can change when new data or new ideas surface or when scientists form new interpretations of what is already "known." (P 4)
Empirical	Science is . . . a set of processes of seeking to understand natural phenomena, to understand our past, and to predict what might happen in the future. Religion and philosophy have these same goals, but a major distinguishing factor is the empirical nature of science. Scientists are consistently seeking physical evidence for their conjectures. They do not rely on divine or purely logical arguments to support their ideas as religion and philosophy do. To some extent evidence separates science from religion and philosophy. (P 1)
	To my mind, science demands evidence and its claims should be consistent with observations of the natural world. An example would be what happened in the case of the "N" rays. I don't think religion or philosophy have this demand. (P 4)
Inferential	I think that this [atomic structure] is a viable model, but I am not certain that it is a mirror of reality . . . It is the most viable model we have had so far and there is a lot of evidence supporting it and there is merit to it. It is very useful. I am familiar with the process and steps they went through to get this model but at this point it's "truth" is somewhat like testing that cylinder you gave us in class that had the strings coming out of it. We can not really compare the insides, all we can do is observe it's tendencies and see if the theory produces the same effects. (P 2)
Creative and Imaginative	If no imagination was needed, induction would be possible and all the pieces of data should spell out the theory, but I realize this never happens. It takes creativity in order to know what data to collect and how to interpret it. I am so impressed with the patterns that scientists see in their data. I believe that that is one of the reasons that Einstein was so amazing. He could look at the same data or information that was available to others and he would see something different. (P 2)
Theory-laden	Science is not as objective as people would like to believe. When presented with evidence, people interpret it differently. The scientists involved in the debate about the extinction of dinosaurs each come from different paradigms. They interpret their evidence according to their own paradigm. Each group invariably will come across data / observations that do not fit within their framework. Sometimes this is dealt with by changing assumptions or interpretations in order to accommodate the new information without changing the structure. (P 1)
	Just because scientists have access to and use the same set of data to derive their conclusions doesn't mean that they are going to come up with the *same* conclusions . . . Their conclusions are surely consistent with the evince but also somewhat based on what type of training and education they have received, their personal belief system, their own imaginations, etc. (P 4)
Theories *vs.* laws	A scientific law is a statement or an equation that attempts to describe a phenomenon. A scientific theory is a statement or group of statements that attempts to explain this phenomenon. An example of a scientific law is Boyle's Law from which we know that if the volume of a gas is increased, then the pressure of the gas will decrease. However, it does not tell why this happens. The kinetic molecular theory, however, attempts to explain Boyle's Law. Thus, a scientific theory attempts to explain a phenomenon, while a scientific law just attempts to describe it. (P 3)

Table 3 (continued)

NOS aspect	Illustrative quote of naïve views
Nature and function of theories	Theories are likely to change, but they are still important. Theories give us an organized way to understand our observations and to use them to predict the outcomes in additional, similar situations. We do not know the absolute truth, though. We just accept our theories as "true" until something raises dissatisfaction with a theory *and* a better theory comes along. A good example is the phlogiston theory of matter. For years, the phlogiston theory was accepted as truth. Anomalous observations about the mass of burning metal caused many to be dissatisfied with the explanations of the phlogiston theory, but they could not reject it unless they had a better explanation. That came about in the oxygen theory of burning. (P 1) Although scientific theories do change, we learn them and teach them because they are valid and substantiated arguments that predict, explain, and provide conceptual frameworks for further research in a certain area. (P 4)
Social and cultural	Science is a community. Science is not practiced in isolation. While some observations related to science may transcend society (a ball falls back to earth when you throw it, the sun rises every morning, the moon cycles through phases, if you mix baking soda with vinegar it foams up), but every society will have its own terms and its own explanations for the phenomena. Science is dictated by the values and beliefs within a society. Science is not practiced in an ivory tower, and it is not isolated from every day life. The scientist is influenced by his religious beliefs, societal pressures and norms, and personal beliefs. The scientist is expected to operate within his scientific community, to have discourse with community members, and to work together. To say that science is outside of culture is to deny the fact that the scientist himself is a part of a larger culture, and a functioning member of a scientific community. It is not possible for science to be unaffected by such things. (P 1)

> Imagine teaching a class where you have to say "This is a law, now a law is not necessarily something that should be true all the time, because it could potentially be changed." How are you ever going to get the students' attention or have them do all the work if you say science is not a sure thing? (M 25, reflection paper)

An additional 25% of participants noted that even though they were convinced that more accurate views of NOS should be taught to students, they believed that this would not be possible. These participants cited one of three reasons to justify this belief: (a) the target NOS ideas would not be of interest to students, (b) NOS ideas are generally too abstract and complicated for students to understand, and (c) given the amount of content that teachers have to cover, little time will be left to address topics such as NOS:

> I seriously think that these ideas about the nature of science might be too difficult for school students to understand. I think it is okay to explain science as it has been taught in the past (it gives them a structured sense of science), even if we convey some erroneous ideas about the nature of science. It is the job of later education to correct these ideas and give students a more accurate view of science. (M 18, reflection paper)

> I do not think, though, that I will have the time to teach them [future students] about the nature of science concepts. I will barely have time to cover all the other basic stuff that is required of me (like photosynthesis, chemical reactions, laws of motions, . . .). (M 8, reflection paper)

The above results are by no means new or unusual in the case of preservice secondary science teachers (see Abd-El-Khalick et al., 1998). Helping teachers to internalize informed views of NOS does not automatically translate into them internalizing its importance as a curricular goal or realizing that it could be taught as part of the "regular" science curriculum. These results, nonetheless, provide the backdrop for understanding the importance of the results obtained in the case of the POS group participants.

In their first two reflection papers, the perceptions articulated by the POS group participants regarding the implications of the philosophical and NOS ideas discussed in the course to science teaching were generally not different from those of the Methods group participants. These reactions primarily focused on *whether* it is possible, and *how* to teach students about the specific NOS ideas they have just "learned." However, starting with the third reflection paper, a shift was evident in the thinking of 3 of the 4 POS group participants. They went one significant step further and started to contemplate the changes in their teaching practices, including discourse, behaviors, and assignments, that are entailed by the sort of NOS understandings they have internalized. This important shift in thinking is evident in the following representative quotes:

> In my previous reaction papers I was, for the most part, preoccupied with thinking about incorporating things I have learned from this class into my own teaching. In a sense I was thinking about how to teach my own students what I am learning in this class. Now I realize that this might have been a naïve way to think about this matter. After all, many of these ideas are too complex and I struggle with trying to understand them myself. My thinking now is more on how these ideas about how science really works will change the way I teach; the way I talk about science; the kinds of labs my students will do; and the way I will ask them to think about science. (P4, reflection paper #3)

> After doing all these readings, I believe I understand why many philosophers of science would agree that the science that is taught in schools is not the science that is practiced by the scientific community. In the science I have learned, science was the "truth". Never questioned. Never debated. My teachers did not use words like "scientists believed" so and so, or they "think" so and so. It was always a statement of the facts. In my own teaching, I need to be very careful about the language and terms I use. Probably terms about truth and certainty should not be used when teaching science. (P1, reaction paper #4)

Instructional Planning Related to NOS

Consistent with previous research findings (e.g., Abd-El-Khalick et al., 1998; Bell et al., 2000; Lederman et al., 2001), the translation of participant preservice teachers' acquired NOS understandings into instructional planning related to NOS was minimal. The lesson plans of only 4 of the 28 participants in the Methods group (14%), who received explicit reflective NOS instruction, included explicit instances of planning to teach about NOS. Of these participants, three were undergraduates and one was a graduate student. These participants' lesson plans included specific NOS-related instructional objectives, such as "The students will be able to discuss the level of authority that science allows (science is never 100% absolutely the truth)" (M 11, lesson plan #2), and "Students will be able to defend the validity of the constructed model based on the agreement of its predictions with the observations of the phases of the moon that they made" (M 1, lesson plan #1). Two of these participants planned to teach about the distinction between observation and inference, and the empirical and tentative NOS. The third participant addressed the explanatory and predictive nature of scientific models and the process of validating such models. The fourth participant explored the interactions between science and social values through planning for her students to investigate and discuss the priority given to funding research on AIDS.

The NOS-related instructional objectives were coupled with relevant activities and/or discussions. For instance, one of the aforementioned four participants simply chose to "lecture" about NOS for the better part of his lesson. Another created a scenario involving a black-box activity, which was different from those activities presented in the methods courses. According to this scenario "scientists unearthed a mystery box . . . . with a set of extremely valuable and fragile items that are covered with a cloth" (M 11, lesson plan #2). Students were expected to feel the items through the cloth without ever removing the cloth, draw inferences about the nature of the items, and come up with a story about the event that must have involved these items. The activity was followed with a set of questions designed to help students discern the differences between observation and inference, and realize the tentative nature of their stories given the available evidence.

To be sure, the lesson plans of several Methods group participants included instructional objectives that were related to science process skills. Indeed, 11 of the 28 Methods group participants (39%) planned instructional activities aimed at providing students with opportunities to—among other things, draw conclusions based on observations, interpret tabular data and graphs, control variables, and design experiments. These instructional activities, however, lacked any explicit and/or reflective components that addressed relevant NOS aspects, such as the variety of methods that could be used to reach evidence-based answers to questions of interest, the limitations associated with the use of positive instances to ascertain the validity of a hypothesis, or the role of expectations, prior knowledge, and theory in influencing the design of experiments. As such, these participants failed to capitalize of these opportunities to plan to teach their students something about the nature of generating and validating scientific claims.

By comparison, 2 of the 4 POS group participants planned to teach about NOS. Like their counterparts in the Methods group, they included NOS-specific instructional objectives and coupled them with instructional activities and explicit discussions. One participant planned to teach students about the inferential and tentative nature of scientific claims using a black-box type activity, while the other planned for her students to investigate the historical development of major geological theories in the context of a unit on the theory of plate tectonics. This latter participant aimed to teach her students about tentativeness of scientific theories and the role of reinterpreting evidence in theory change.

Even though the other two POS group participants did not explicitly plan to teach about NOS, a noteworthy aspect of the lessons they planned during the latter half of Spring term (lesson plans 3 and 4) was their use of language that was consistent with accurate conceptions of NOS. When their lesson plans included objectives targeting science process skills, such as designing experiments and testing hypotheses, these two participants included questions or explicit statements that alerted students to some NOS-related ideas, including that positive evidence does not "prove" a hypothesis or that having others check the results of one's experiment would "help reduce the bias" inherent in any one individual's interpretations and conclusions. Even though these instances were few in number, they were consistent with the shift that was evident in the POS group participants' comments regarding the implications of learning about NOS for their own teaching. As noted above, these participants shifted their thinking from a preoccupation with whether secondary students could understand the NOS ideas they were learning about in the POS course and how to best teach secondary students about these ideas, to the realization that these NOS ideas have implications for the way these participants would teach science in their future classrooms. Moreover, these instances indicate that having deep understandings of NOS potentially enables prospective teachers to capitalize on certain instances (e.g., when teaching science process skills) and teach about NOS in the context of "regular" science sessions versus ones specifically intended to teach about some aspect of NOS (which many teachers view as an add-on to their teaching). This was not the case with the Methods group participants. As noted above, many of these participants included science process skills objectives in their lesson plans but none planned to utilize these instructional episodes to teach something about NOS.

Discussion and Implications

This study indicates that the investigated POS course resulted in deeper understandings of NOS on the part of participants. It should be noted, however, that (a) participants joined with the POS course after having been explicitly sensitized to the target NOS aspects in the Science Methods I course, and (b) the POS course was specifically designed to influence participants' views of these aspects and was coupled with relevant readings from history and practice of science. The present results, thus, cannot be generalized to other POS courses. More importantly, exposure to POS coupled with explicit reflective cues regarding the implications of the course content for science teaching resulted in moving participants beyond the customary discourse of our previous participants (e.g., Abd-El-Khalick et al., 1998; Lederman et al., 2001) regarding whether it is possible and how to teach specific NOS ideas to K-12 students, to the present participants thinking about their own teaching behaviors in relation to NOS. Finally, the genesis of a NOS PCK was evident through the POS group students' use of specific examples from history and practice of science in their discourse, and plans to teach, about NOS. However, these results should be viewed with caution given the relatively small number of prospective teachers enrolled in the POS course. This study indicates that more concerted and extended efforts that go beyond a few hours of NOS-related instruction in a science methods course should be undertaken if we desire science teachers to address NOS instructionally. Finally, the significant question of whether the NOS views and understandings of the POS group students will translate into actual classroom practices remains to be answered. This question will be pursued after these students go into teaching.

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PERFORMANCE ASSESSMENT IN SCIENCE METHODS: A PROGRAM DESCRIPTION

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National and state educational reforms have recommended that students become more involved in their own learning based on the philosophy that student understanding is facilitated by active involvement. These reforms (e.g., AAAS, 1993; 1995; NRC, 1996; WSCL, 1998 [hereafter referred to as "reform documents"]) call for teaching that will motivate students to become reflective, constructive, and self-regulated learners. Educational reforms require that students not only answer questions accurately, but be able to explain the process they used to derive their response. As school districts around the state and the country have developed and utilized techniques to improve student communication skills (especially in literacy), the focus has now become utilization of those skills in the areas of math, science, and technology. In a world that has become increasingly focused on information technology and telecommunications, it is imperative at the local, state and national level, that students are actively engaged and enthusiastic about learning and utilizing technology in math, science, and writing. There is already a severe shortage of graduates with expertise in these areas and that shortage is increasing at a rapid rate (NSF, 1996). The first and best response is to enhance and improve the training of teachers in math, science, and technology. Part of training the teachers to be able to teach math, science, and technology is to help them recognize what constitutes outstanding student work in these areas. The use of performance assessment is recommended to assess whether students can conceptualize important science and math concepts (i.e. Shymansky, Chidsey, Henriquez, Enger, Yore, Wolfe, & Jorgensen, 1997). Indeed, well-designed assessment tasks can not only assess student understanding but also teach concepts (Darling-Hammond &

Falk, 1997; Shepard, 2000). Performance assessment is particularly well-suited to this purpose because it focuses on having students apply knowledge in an authentic context for an authentic purpose.

Below we discuss needs for preservice science and math teacher education. We then describe a program designed to meet those needs.

Call for New Forms of Assessment

Following the release of NCTM's *Curriculum and Evaluation Standards* (1989), AAAS's *Benchmarks for Science Literacy* (1993) and NRC's *National Science Education Standards* (1996), many states and local school districts have developed standards for students' learning in mathematics and science. Included in these standards and in NCTM's recently published update to the *Standards*, the *Principles and Standards for School Mathematics* (NCTM, 2000), are a greater emphasis on the processes of doing mathematics (e.g., problem solving and reasoning) and on communicating thinking and solution strategies (NCTM, 1989, 2000). In the science realm is an emphasis on science as inquiry and understanding nature of science (AAAS, 1993; NRC, 1996).

Along with new standards for learning is a call for new forms of assessment. Traditional paper and pencil classroom tests and standardized multiple choice tests focused on recall of facts and basic procedures do not effectively measure what is valued for standards based learning (Darling-Hammond & Falk, 1997; Shepard, 2000; Torrance, 1993). While traditional measurement approaches to assessment were once aligned with the instructional practices of a century past, these approaches are not consistent with current teaching and learning goals from a social constructivist perspective (Shepard, 2000). This incongruity has resulted in an emerging paradigm for assessment that involves teachers' assessment of students' understandings and students' self-assessments as part of the social process of knowledge construction (Shepard, 2000). Educators and researchers argue that to align assessment with the social constructivist perspective underlying standards based learning, the following changes are needed: (a) the form and content of assessments must represent higher order thinking, reasoning, communication, problem solving skills, as well as a conceptual understanding of subject matter; and (b) the focus of assessment policy needs to shift to using assessment for learning (Borko, Mayfield, Marion, Flexer, & Cumbro, 1997; Darling-Hammond & Falk, 1997; Shepard, 2000).

Consistent with these views, in mathematics and science education the *Standards* state that the primary purpose of assessment should be to support the learning of important mathematics and science. It should furnish useful information to both teachers and students. Assessment should be more than merely a test at the end of instruction to see how students perform under special conditions. To achieve this goal, the *Standards* call for embedding assessment in instruction, rather than keeping assessment as separate from learning (NCTM, 1995, 2000; NRC, 1996). Indeed, this call is supported by research that indicates use of formative assessments in instruction enhances student learning (Black & William, 1998).

As a result of this call, attention has been directed to more authentic forms of assessment, including performance assessment. Indeed, well-designed performance assessment tasks can not only assess student understanding but also teach concepts (Darling-Hammond & Falk, 1997; Shymansky, Chidsey, Henriques, Enger, Yore, Wolfe, & Jorgensen, 1997; Sheppard, 2000). While a single definition for performance assessment does not exist, Stenmark's (1991) definition for performance assessment in mathematics education seems to capture the important aspects of this approach. Stenmark (1991) states, "A performance assessment in mathematics involves presenting students with a mathematical task, project, or investigation, then observing interviewing, and looking at their products to assess what they actually know and can do" (p. 13). We have used this definition for both our math and science education components.

Van de Walle (2001) expands on these ideas by proposing the following three criteria for a good performance assessment task. He states that a task must: (a) begin where the students are, regardless of their mathematical prowess; (b) be problematic due to the mathematics that the students are to learn, not due to the context of the problem; (c) require justifications and explanations for answers and methods (p. 66).

Beyond these definitions of performance assessment, educators and researchers argue that the advantages of classroom based performance assessments are that they provide the opportunity to:

1. Examine the process as well as the product and represent a full range of learning outcomes by assessing students' writing, products, and behavior (Danielson, 1997; Shepard, Flexer, Hiebert, Marion, Mayfield, & Weston, 1996).

2. Situate tasks in authentic, worthwhile, and/or real-world contexts (Stenmark, 1991).

3. Preserve the complexity of content knowledge and skills (Shepard, et al., 1996; Shymansky, et al., 1997).

4. Assess higher order thinking skills and deeper understandings (Firestone, Mayrowtz, & Fairman, 1998).

5. Embed assessment in instruction, rather than separating it from learning (Stenmark, 1991).

6. Apply criterion referenced assessment approaches based on important learning outcomes, rather than norm-reference (Stenmark, 1991).

Performance Assessment to Improve Teaching and Learning

Early research indicated that using performance assessment in instruction can improve student learning. Fuchs, Fuchs, Karns, Hamlett, and Katzaroff (1999) studied the effects of classroom based performance-assessment-driven instruction. They found that students in performance assessment-driven instruction classes demonstrated stronger problem solving skills than comparison groups that were not performance assessment-driven.

Kelly and Kahle (1999) found similar results in science. Students who took performance assessment tests were better able to explain their reasoning and conceptions than students who took traditional tests, leading to the conclusion that they had stronger understandings, perhaps as a result of working through the performance assessment task.

Shepard, Flexer, Heiber, Marion, Mayfield, and Weston (1996) also investigated whether using performance assessment in instruction improved student learning in mathematics. While they found little improvement in student achievement, they believed that more time was needed to realize change from students. However, they found that the teachers involved in the study were beginning to show substantial changes in practice. The changes included: greater use of manipulatives; increased emphasis on the teaching and learning of problem solving strategies; and increased class time and focus on written explanations in mathematics. Similarly, in Borko, et al.'s (1997) study of a professional development program on using performance assessment strategies in mathematics instruction, they found that their teachers changed their instructional practices to incorporate: using more problem solving activities; requiring student explanations of strategies as a central component of their programs; developing and using scoring rubrics for assessing students solutions of open-ended tasks. These changes all represent a shift in the direction of the vision for standards-based instruction.

While it is possible to derive many instructional benefits from performance assessment strategies, it is not clear that teachers can easily or quickly learn to implement these strategies in practice. Firestone, Mayrowetz, & Fairman (1998) studied teachers in states where state testing programs included performance assessment tasks, and therefore, teachers were being compelled to use performance assessment in instruction to prepare their students for state tests. The researchers found that moderately high-stakes testing combined with some professional development opportunities, generated considerable classroom activity focused on the test itself, and promoted changes to align curriculum with the tests; however, little change in instructional strategies resulted. Firestone, Mayrowetz, & Fairman (1998) identified two major barriers to change: a lack of the sophisticated content knowledge required in implementing performance assessment approaches; and a lack of rich tasks and problems in the curricular materials to support this approach to instruction. To elaborate on the first barrier, the researchers found that the teachers had limited views of what constituted practical applications of mathematics. The teachers' conceptions generally focused on shopkeeper math (e.g., balancing a checkbook, calculating the discount on sale items, or measuring ingredients for cooking), and their tasks emphasized lower level skills rather than the more challenging analytical and reasoning skills required for using mathematics in engineering, finance, marketing, and statistics. Firestone, Mayrowetz, & Fairman (1998) concluded that to effectively implement performance assessment and thereby realize the potential for improved student learning, teachers needed substantive training opportunities (not just new policies requiring new assessment approaches) and new curricular materials that are aligned with performance assessment strategies and a standards-based vision for teaching and learning.

Shymansky, et al. (1997) found similar results in their study conducted of science teachers and science educators. These teachers and science educators developed five different performance assessment tasks for grade 8-9. When administering the tasks, they found that students performed poorly on these tasks, calling into question whether the tasks were poorly designed, or whether the students simply did not know how to take the tests. They also found how complicated it was to design performance assessment tasks that were truly valid.

In accordance with Firestone, Mayrowetz, and Fairman's (1998), and Shymansky et al. (1997) research results, Borko, et al. (1997) found that substantive and sustained professional development is needed for teachers to effectively use and realize the benefits for performance assessment approaches. Their research indicated that important features of their program included: situating the change process in the actual teaching and learning contexts where the new ideas will be implemented; fostering supportive learning communities of teachers as they learn about new approaches and as the attempt to make changes; and providing staff development personnel with specific expertise to facilitate change by introducing new ideas based on teachers' current levels of interest, understanding and skill. Along with these features that enhances their program, Borko, et al. identified two barriers not discussed by Firestone, Mayrowetz, & Fairman (1998). First, Borko, et al. Found that teachers' beliefs need to be recognized and a primary focus of professional development efforts in performance assessment approaches. They believed that their project would have been more successful in effecting change in practice if they had addressed teachers' beliefs more directly. As Firestone, Mayrowetz, & Fairman reported, Borke, et al. found that many of their teachers had a limited view of mathematics and appropriate strategies for teaching mathematics that were inconsistent with the standards-based vision of mathematics. These views needed to be confronted for substantive change to occur. Without confronting these beliefs, teachers tended to either ignore new ideas of assimilate them into existing practice, instead of making major shifts in practice. Second, Borko, et al. found that time was a major obstacle to changing classroom practice. In particular, competition among priorities for limited classroom time was problematic. For implementing performance assessment approaches, time served as a barrier in: planning for the implementation of new strategies; applying more complex scoring rubrics in assessment; administering the assessment tasks; recording observations of students working and thinking as part of the assessment; and interviewing students before, during, and after the assessment. For successful change to occur, teachers need time for implementing new assessment approaches.

Recognizing the value of performance assessment and the complexity of using these strategies, we decided to make performance assessment a focus of our mathematics and science methods courses. This decision was part of our effort to prepare our preservice teachers from the beginning of their careers to use these approaches and to implement standards-based teaching and learning in their own instructional practice.

Situated and Constructivist Perspectives on Teacher Learning

With the goal of developing preservice teachers' abilities to implement performance assessment in their classrooms, we considered a second need identified in teacher education literature: a need to situate preservice teacher learning in classroom practice. Borko, et al. (1997) emphasized the importance of this approach for professional growth. They found that a key component of their program was their teachers' ability to experiment with and implement the ideas of the professional development workshops in their own classroom practice, and then to reflect on these efforts in follow-up workshops.

This finding is consistent with the perspective of teacher learning put forth by Putnam and Borko (2000). They argue that for teachers to construct new knowledge about their practice the learning needs to be situated in authentic contexts. First, learning needs to be situated in authentic activities in classrooms to support transfer to practice. For preservice teachers, a combination of university learning for theoretical foundations and school-based learning for a situated perspective is needed (Putnam & Borko, 2000). Second, preservice and inservice teachers should participate in discourse communities as part of learning and enculturation in the profession. Preservice teachers, in particular, need to learn about and contribute to a community's way of thinking (Putnam & Borko, 2000). This process of enculturation is especially important for future teachers of mathematics or science because many come to their education program with limited views of teaching, learning, and doing mathematics (Roth-McDuffie, McGinnis, & Graeber, 2000).

Spector (1999) recommends having preservice teachers work with inservice teachers to help them better apply newly learned teaching and assessment strategies. This finding falls in line with Dickinson, Burns, Hagen, and Locker (1997) finding that within the teaching context and support of an enthusiastic peer, important changes in science teaching can take place.

Putnam and Borko (2000) recognized that implementing this perspective in teacher preparation programs can be problematic. While we want to place preservice teachers in schools to experience the activities of teaching as part of their learning, K-12 placement classrooms may not embody the kind of teaching and learning advocated in university classrooms and/or these kinds of classrooms may not be available. Moreover, the pull of traditional school culture is strong, and these traditions make it difficult for student teachers to go in with different approaches and views (Putnam & Borko, 2000).

One solution to achieving a situated context while overcoming the problems of school placements is to use case-based approaches for preservice teacher learning. This approach provides shared experiences for preservice teachers to examine together and allows for the teacher educator to control the situations and issues that arise (Putnam & Borko, 2000; Sykes & Bird, 1992). Another approach is using professional development schools that also provide for greater control and monitoring of the preservice teachers' experiences (Putnam & Borko, 2000). While we want to mention these options for consideration, these approaches are not the focus of this program.

The paper describes the design of the project in its first year of implementation. The Project is a Professional Development Program that pairs inservice and preservice teachers together in small groups to develop performance assessment tasks that include the content areas of mathematics and science. By bringing inservice and preservice teachers together to collaborate on a meaningful design project, we are creating a new model for professional development by creating a "bridge" that enables the development of networking and mentoring opportunities, and builds a sense of community. The "bridge" of professional development activities for preservice and inservice teachers will establish and cement important relationships among participants that are foundational in assuring their long-term success.

Description of the Course

The current study took place in a one-semester K-8 science methods course. There were nineteen students enrolled, working on a Master in Teaching (MIT) degree. This science methods course was the only course they would take to prepare them to teach science. In addition to designing and administering the performance assessment task with the help of their mentor teacher, other assignments in the course were: (a) study a content area, design and administer an interview of a K-8 student to identify student ideas, (b) design lessons to address those ideas, (c) participate in hands-on, minds-on activities in class, (d) submit weekly reflection papers on assigned topics, (e) participate in weekly hands-on activities designed to improve nature of science conceptions.

Intervention

We first implemented our Performance Assessment program in a preservice graduate science methods course at Washington State University Tri-Cities in the Fall 2001 semester. This methods course focused on science teaching and learning at the K-8 level. The students in the science methods course were concurrently enrolled in an advanced educational psychology course, and would take a mathematics methods graduate course and design a performance assessment task for that course as well as a part of this project.

A collaborative team composed of a mathematics educator (Amy Roth McDuffie), a science educator (Valarie Akerson), two middle school mathematics teachers (Tammy Droppo and Troy Fulton), a math/science coordinator from the Educational Service District (Judith Morrison) and a secondary program administrator from a Washington State Educational Service District (Mike Kirby) planned the performance assessment program at the beginning of the semester, and adjusted the program as needed during the semester. Mrs. Droppo, Mr. Fulton, and were recognized regionally as teacher-leaders for their expertise in performance assessment strategies, and more generally, for implementing standards-based approaches to teaching and learning. During the semester, Mrs. Droppo and Mr. Fulton recommended other teachers so we had a cadre of teachers at different levels to work with our preservice teachers. A key component of the program was providing for meaningful interaction between preservice teachers and inservice teachers to facilitate the preservice teachers enculturation to the teaching community, as called for by Putnam and Borko (2000).

Introductory assessment workshop. The workshop was conducted during the regular methods class meeting time for a three hour period. The collaborative team planned and facilitated the workshop with team members leading different parts of the workshop. It was conducted to: briefly discuss general assessment issues (some discussion of assessment occurred prior to this workshop); provide an overview of the standards-based assessment program in Washington State (e.g., see Washington Commission on Student Learning, 1998); and introduce the preservice teachers to performance assessment issues and strategies.

To introduce the preservice teachers to performance assessment we asked them to work in groups on sample performance assessment task that was written and field-tested as part of an assessment program in Washington State. Unfortunately, the teacher-leaders who administered the tasks were mathematics instructors, and thus, the example task was a mathematics task. The task required the preservice teachers to design a cereal box that would reduce the amount of cardboard needed and still maintain a specific volume, and then to write a letter to the cereal company describing and defending their design. While we only provided approximately twenty minutes for the preservice teachers to work on the task, they had enough time to identify key issues of the task and key components of task-design. Next, we discussed some of the features of the task (e.g., an open-ended question; the descriptive and persuasive writing componet; the multiple entry points and various solution methods possible in performing the task, etc.). After a brief discussion of the task, we gave the groups scoring rubrics and samples of ninth grade students' work on the task at various performance levels. Using the scoring rubrics, the groups assigned scores to their sample students' work. Following this group work, we discussed the scoring process, the rubrics, and the task as a class.

Next, we worked to formalize their knowledge of performance assessment by discussing defining characteristics of performance assessment, advantages, and limitations. Additionally, a middle grades language arts teacher-leader facilitated a brief discussion of types of writing used in performance assessment (e.g., descriptive, expository, and persuasive). We concluded the workshop with an introduction of the planning guide and provided a few minutes for generating ideas for the preservice teachers' PA projects.

Researching topics and generating a plan for the PA task. The preservice teachers worked individually to generate performance task ideas that related to their content area of study. The performance assessment task was related to their earlier student interview and lesson plan assignments. The preservice teachers selected a range of grade levels at which they would be most interested in designing and implementing a performance assessment task.

Each preservice teacher submitted a planning guide that outlined the major features of their task. An important part of this planning guide was aligning the task with standards for learning. Because the Washington State Essential Academic Learning Requirments (EALRs; Washington Commission on Student Learning, 1998) were emphasized in this course, our students identified appropriate EALRs for their task. From this point, the groups continued developing their tasks outside of class time. While many groups created original tasks, the preservice teachers were permitted to use outside resources (e.g., activity books, journal articles) for ideas for their task. Even in the cases where a problem, activity, or task was used from an outside source, significant work was required to develop the problem into a performance assessment task and meet the assignment requirements.

Matching mentors and preservice teachers. Using the information provided in the preservice teachers' planning guides, we matched each preservice-teacher to a mentor teacher. This matching was done based on the topic, skills, abilities, and level of thinking required for the PA task and the knowledge and grade level of the mentor teachers' students. The preservice/inservice teams were assigned by the ESD, and initially met on their own after contacting one another by phone or email. Mentors were sometimes assigned more than one preservice teacher.

After the mentor teachers had been assigned to groups of preservice teachers, the mentors attended one hour of a methods class. The preservice teachers brought their planning guides and drafts of their PA tasks to this meeting. During this hour, the mentor teachers met with each of their preservice teachers to discuss their ideas and plans for the PA tasks. Additionally, other members of the planning team (Dr. Akerson, Dr. Roth McDuffie, Dr. Morrison) were available to assist groups in designing their tasks.

Submitting the first draft and field-testing the PA task. On the eighth week of the semester, the groups submitted their first drafts of their PA tasks to their science methods professor and to their mentor teacher. Within a week, both parties provided written feedback and comments for the groups to consider before administering their tasks to students.

Each group arranged a time to field-test their PA tasks in their mentor's class. The tasks were designed to be completed in one to three 50 minute class periods. Each mentor teacher decided with his or her groups who would facilitate the task. In some cases the mentor teacher was the primary facilitator and in other cases the groups facilitated the task administration. However, in all cases, the preservice teachers observed throughout the task administration, talked with students (and in some cases, interviewed students about their thinking), and recorded notes on the process.

Analyzing results and reporting on the PA task. Following the field-test, the preservice teacher groups scored the students' work and analyzed selected students' work in greater depth. Finally, they prepared a written report of their findings and their reflections on the performance assessment process and project

Data Collection

To track results of design, administration, and conceptions of what constitutes a performance assessment task a variety of data were collected. Prior to the introduction of the program a baseline understanding of the preservice teachers' conceptions of performance assessment was designed through surveys and interviews of all ten students who met interview criteria. The interview criteria consisted of (a) being officially enrolled in the Master in Teaching cohort, (b) being concurrently enrolled in advanced educational psychology course, and (c) the intention to take math methods in the spring. (See Appendix A for interview protocol.) In addition to the interviews, both researchers kept independent logs of their perceptions of preservice teacher understandings of performance assessment and the challenges of program implementation. To track administration of the task student reflections were collected, and videotapes were made of as many preservice teachers as possible.

To address logistical issues of the field-based component the researcher logs, discussions and emails with preservice teachers, and final performance assessment task reports were collected. This data allowed development of a profile of the project in order to make recommendations for future implementation.

Data was collected from the inservice teachers involved in the project through a survey (see Appendix B) sent to them through the mail after the preservice teachers had completed their field work in the classroom. The inservice teachers were asked about their understanding of performance assessment, how they implement it in their classroom, and their rating of the preservice teacher's performance assessment task implementation. The inservice teachers were asked if they had learned anything about performance assessment through their mentorship experience and if they had suggestions for future similar projects.

Data Analysis

To conduct the preliminary analysis of this on-going research project the researchers and a graduate student sorted through all data currently collected. This data was used in an interpretive fashion to develop early categories in response to the research questions.

To determine preservice teachers' understandings of performance assessment, preservice teacher responses to interview questions were coded using the scheme developed by Fuchs, Fuchs, Karns, Hamlet, and Katzaroff (1999). Interview responses were coded a one (1) or a zero (0) indicating preservice teachers included items that showed understanding of performance assessment in their responses. The final tasks were coded with the same scheme indicating items that showed whether an understanding of performance assessment was included in the tasks. It should be noted that the coding scheme does not determine how well the tasks were developed, but whether the responses or tasks included components that indicated how well they understood performance assessment.

Preliminary Findings

We are currently in the process of completing our comprehensive data analysis. Presentation of final results in will likely take place next January. However, we report a preliminary analysis of understandings of performance assessment and perceptions below.

Understandings of Performance Assessment

Prior to intervention the preservice teachers had very little understanding of performance assessment as indicated by low scores on the coding scheme (Fuchs et al, 1999). The preservice teachers included very few of the components necessary to a performance assessment task: their examples tended to be short, required single answers, and did not provide opportunity for their students to generate ideas. Additionally, none of the preservice teachers required students to explain their work, nor to generate a written communication about their work. Their idea of performance assessment was not couched in an authentic task.

From videotapes, questionnaires, and interviews, it was apparent that the preservice teachers continued to hold minimal understandings of performance assessment even after being introduced to it in their Advanced Educational Psychology class and after the performance assessment night in the science methods course.

Following the interventions, and especially upon developing and administering their own tasks, the preservice teachers' understandings of performance assessment improved greatly, as indicated by scores on the coding scheme (See Appendix C). All preservice teachers required from their students written explanation of strategies, modeling of strategies, and multiple questions that required application of knowledge set in an authentic context. Most of the tasks developed by the preservice teachers required their students to generate ideas and information rather than memorize or provide single answer responses.

Perceptions of Mentor Teachers

The inservice, mentor teachers provided feedback on the project on the survey they were sent in the mail. Some of the teachers had had an introduction to performance assessment in the past, usually through workshops provided in their schools. Some had had no experience with performance assessment. The overall impression was that they did not fully understand performance assessment and could not adequately rate the preservice teacher's implementation of the performance assessment task. The feedback on the project was positive from the mentor teachers, one teacher said they thought it was "another excellent way for students to get into the classroom."

Perceptions from the Educational Service District (ESD)

The collaboration between the ESD and the university allowed this project to begin to build strong relationships between university faculty and students, inservice teachers, and ESD employees. This relationship will develop in the future and undoubtedly result in stronger understandings between all involved. The ESD was able to offer a stipend to the participating inservice teachers which compensated them for the time they put into the project. Inservice teachers should not be expected to devote time outside of their regular duties without compensation.

The data show that the mentor teachers involved in the project had little experience or knowledge about performance assessment. In light of this, the ESD has committed to involve more inservice teachers in performance assessment training workshops and experiences

Implications

While students did grow in their understandings of performance assessment, there is still much work to be done. Most importantly, details regarding partnerships built between inservice and preservice teachers need to be ironed out. Specifically, inservice teachers of the right grade levels and content areas, who have appropriate levels of knowledge of performance assessment need to be found. Also, better mechanisms for matching these inservice teachers with preservice teachers need to be developed in order to eliminate preservice teacher frustrations and allow them to focus on the performance assessment itself.

Probably the most positive comments from the preservice teachers regarding the whole assignment were that they were pleased to be working with actual students. This finding is in line with the Putnam and Borko (2000) finding that a situated perspective is most meaningful to learning. When asked whether they would rather teach a lesson to actual students or to administer the performance assessment task, the preservice teachers indicated they would prefer to do both. They believed the performance task was valuable, and that they learned a lot from the experience. It seems it may be necessary to actually create and administer the task for preservice, and even inservice, teachers to develop an appropriate understanding of performance assessment.

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Appendix A

Pedagogical Beliefs in Mathematics Survey / Interview Questions
(Adapted from Peterson, et. al., 1989)

1. A. Describe, as specifically as you can, a lesson in which you introduce a *new* mathematics topic to your class. We are interested in the way you organize and present the mathematics content, as well as the specific teaching methods and strategies that you use. Preservice teachers: *imagine* a lesson and describe it (if you have not had experience teaching a new mathematics topic). Inservice teachers: *recall* a particular lesson and describe it.

   B. How does your *introductory* lesson differ from a *typical* lesson on a mathematics topic?

2. Describe, as specifically as you can, a lesson in which you introduce a new science topic to your class. We are interested in the way you organize and present the science content, as well as the specific teaching methods and strategies that you use. Preservice teachers: *imagine* a lesson and describe it (if you have not had experience teaching a new science topic). Inservice teachers: *recall* a particular lesson and describe it.

   B. How does your *introductory* lesson differ from a *typical* lesson on a mathematics topic?

3. Describe, as specifically as you can, a lesson in which you include elements of the Nature of Science. We are interested in the way you organize and present the philosophy, as well as the specific teaching methods and strategies that you use. State specifically the elements you included. Preservice teachers: *imagine* a lesson and describe it (if you have not had experience teaching science). Inservice teachers: *recall* a particular lesson and describe it.

4. Describe, as specifically as you can, a lesson in which you include writing in mathematics and/or science activities. We are interested in the role of writing in the lesson and the type of writing expected, as well as teaching methods and strategies that you use with writing. Preservice teachers: *imagine* a lesson and describe it (if you have not had experience teaching a new mathematics and/or science topic). Inservice teachers: *recall* a particular lesson and describe it.

5. What do you think the role of the teacher should be in teaching problem solving and reasoning to students?

6. What do you think the role of the learner should be in a lesson involving problem solving and reasoning?

7. Are there certain kinds of knowledge and/or skills in mathematics that you believe all students should have? If so, what are they?

8. Are there certain kinds of knowledge and/or skills in science that you believe all students should have? If so, what are they?

9. For the grade that you teach (or intend to teach), what do you believe should be the relative emphasis in mathematics on fact knowledge versus understanding topics and processes versus solving of real-world/ authentic problems? Why?

10. What do you see as the relationship between learning of mathematics facts, understanding mathematics concepts and processes, and solving real-world/ authentic problems involving mathematics?

11. For the grade that you teach (or intend to teach), what do you believe should be the relative emphasis in science on fact knowledge versus understanding scientific concepts and processes versus solving of real-world/ authentic problems? Why?

12. What do you see as the relationship between learning of scientific facts, understanding scientific concepts and processes, and solving real-world/ authentic problems involving science?

13. What do you think the role of technology (e.g., calculators, computers, internet-use, etc.) should be in teaching and learning mathematics?

14. What do you think the role of technology (e.g., calculators, computers, internet-use, etc.) should be in teaching and learning science?

15. Students have different abilities and knowledge about mathematics. How do you find out about these differences?

16. Students have different abilities and knowledge about science. How do you find out about these differences?

17. Describe, as specifically as possible, what you understand performance assessment to be, when you believe it is useful, and when you believe it is not appropriate to use. If you have used performance assessment in your teaching, describe how you have used it.

Performance Assessment Interview: Additional Items (Fuchs, et al., 1999)

18. Write and/or describe a mathematics problem that might be categorized as an example of performance assessment.

19. Write and/or describe a science problem that might be categorized as an example of performance assessment.

Appendix B

Performance Assessment Task Mentorship Survey

Name______________________________School_____________________________________

Grade/Subject______________________WSU Preservice Teacher____________________

1. How would you define the term "performance assessment"?

____

2. How often do you do performance assessment in your classroom?

Often (weekly)___Sometimes (monthly)____Seldom (1-2 times/year)____Never____

3. Have you had any classes/workshops/inservices on performance assessment?______

If yes, please describe____

4. Briefly describe your preservice teacher's performance assessment task:____________

5. How would you rate the success of the preservice teacher's performance task implementation?
(This will be held completely confidential)_________________________

6. How well do you feel the student's task met the criteria for performance assessment?
Did the task: a. present students with a task, project, or investigation? **YES NO N/A**

b. establish a meaningful context based on issues/problems, themes, and/or students' ideas? **YES NO N/A**

c. require the application of thinking skills/processes? **YES NO N/A**

d. call for products/performances with a clear purpose for an identified audience? **YES NO N/A**

7. Did you learn anything about performance assessment tasks through this mentorship experience? If so, please describe:____

8. Do you have any suggestions for the improvement of this mentorship project for the future? Please use the back of this form to complete this question.

Appendix C

Coding Scheme for Performance Assessment Elements Present in Tasks or Descriptions of Tasks
(Adapted from Fuchs, et al., 1999)

Code "1" if present, "0" if not present:

Write (describe) a math/science problem that might be categorized as an example of performance assessment:

Contains 2 or more paragraphs
Contains Tables or graphs
Has 2 or more questions
Provides opportunities to apply 3 or more skills
Requires students to discriminate relevant/irrelevant information
Requires students to explain work
Requires students to generate written communication

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USING A WEB-BASED TASK TO MAKE PROSPECTIVE ELEMENTARY TEACHERS' PERSONAL THEORIZING ABOUT SCIENCE TEACHING EXPLICIT

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Many researchers have argued that by the time prospective teachers get to college they hold well-established beliefs and practices related to being a teacher (Pajares, 1992). These beliefs include ideas about what it takes to be an effective teacher and how students ought to behave, and, though usually unarticulated and simplified, they are brought into teacher preparation programs (Clark, 1988 and Nespor, 1987, as cited in Pajares, 1992). Not surprisingly, these views of teaching and learning have been shown to influence classroom teaching practice (Pajares, 1992).

Prospective teachers' theories and beliefs about teaching and learning have been defined by the literature as '*personal theorizing*' (Barone, 1988; Ross, 1992; Schubert, 1992). Teacher theorizing includes the development of their own pedagogical and moral platforms, which, together with more concrete subject matter and social interaction preferences, can result in their own curricular materials and activities (Barone, 1988). As Schubert (1992) argued, teacher educators need to respect the integrity and the sophistication of personal theorizing by prospective teachers as a valuable and necessary form of research and teacher education. Therefore, targeting prospective teachers' personal theorizing is essential to supporting their learning to teach.

The question becomes, "How can teacher educators get an insight into prospective teachers' personal theorizing? One approach to making prospective teachers' personal theorizing transparent is the use of networked technologies that help to make thinking visible (Bransford, Brown, & Cocking, 2000; Collins, 1990). The purpose of this qualitative case study was to examine prospective elementary teachers' personal theories about science teaching and learning and how they changed over time as they engaged in an integrative, web-based task. A secondary purpose of the study was to investigate the role of technology in making prospective teachers' personal theorizing explicit.

Theoretical Underpinnings

This study draws upon two bodies of literature: teaching as community property which pursues the scholarship of teaching (Shulman, 1998) and making thinking visible through networked technologies as a core feature of the cognitive apprenticeship model of instruction (Collins, 1990). It is important to make prospective teachers' views on learning and teaching explicit, to discuss and analyze these views critically, and to encourage prospective teachers to reflect on these views and their implications for science instruction (Aguirre & Haggerty, 1995). As Prawat (1992) argued, "the investigation of teachers' beliefs is a necessary and valuable avenue of educational inquiry" (p. 326).

Making work transparent implies the possibility of peer review, overcoming isolation and improvement of the quality of teaching. Shulman (2000) noted that, "By engaging in purposive reflection, documentation, assessment and analysis of teaching and learning, and doing so in a more public and accessible manner, we not only support the improvement of our own teaching but our colleagues as well" (p. 50). In pursuing the scholarship of teaching, teachers endeavor to make their work and ideas public, to subject them to critical examination, and to exchange them so that others can build upon them (Shulman, 1998). An emerging characteristic of a teacher as a professional is this ability to articulate, evaluate, engage in, and respond to criticism about teaching, their own practice and student learning (Lyons, 1998). Similarly, Shulman (1998) illuminated the importance of communicating ideas:

> Having to take our teaching from the private to the public sphere, having to think about how we are going to engage in it, but also how we will come to understand what we are doing as teachers in ways that will permit us to organize what we do, display and communicate and converse about it to our own community, will have an improvement effect on teaching. (p. 12)

Taking private beliefs, theories and practices from the private to the public sphere has an effect on not only prospective teachers' personal theorizing but on their peers' theorizing as well. But how can we move from the private to the public sphere? Networked technologies have the potential to do that by making thinking visible.

Collins (1990) discussed how networked technologies make the invisible visible and the tacit knowledge explicit. Specifically, he stated that the benefits of technology include making visible the parts of a process that are not normally seen. By revealing these processes in detail, learners will have the chance to figure out how processes unfold. In the case of teacher education, by making their thinking visible, prospective teachers engage in reflective and metacognitive activities about their own learning but also they get a better understanding about their peers' thinking about teaching.

In this study, hypermedia technology was used to support prospective elementary teachers in publicly articulating their personal pedagogical theories, revisiting and revising them over time in light of new experiences and learning within the context of an innovative teacher preparation program.

Purpose and Research Questions

Given the need to incorporate opportunities for engaging prospective teachers in reflection and making their personal theorizing explicit and the potential of hypermedia authoring to support this kind of reflection and make thinking visible, this study aimed to answer the question: What are the prospective elementary teachers' views of teaching and learning science as they became transparent through their web-based philosophies. Specifically, the questions that guided this research are:

1. What is the nature of prospective elementary teachers' philosophies about science teaching and learning?
2. In what ways does the web-based portfolio task support thoughtful reflection associated with learning to teach science?
3. In what ways does the technology contribute to the portfolio task?

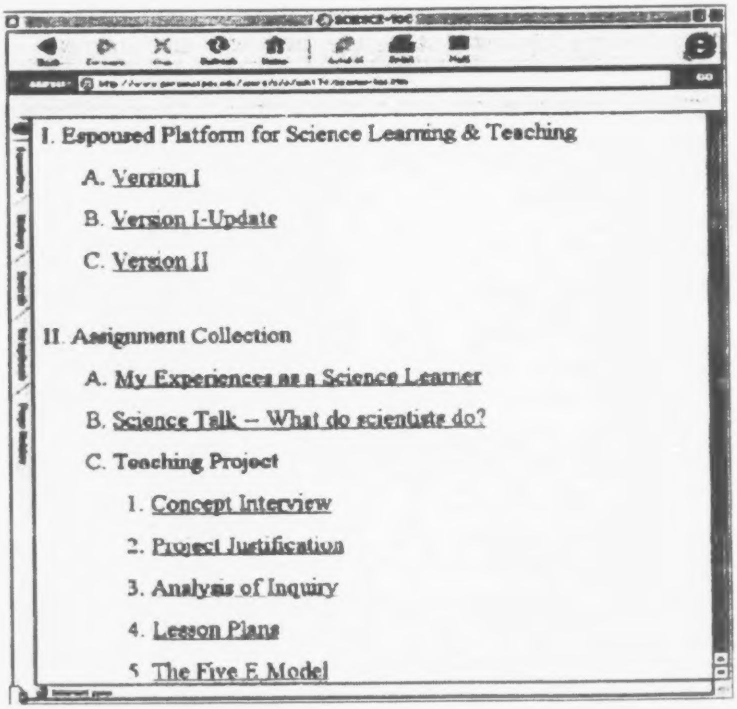
Research Methods

Design

This study manifests the characteristics of a multi-participant case study (Merriam, 1998). For the purpose of this study, two individuals were investigated within the larger case of prospective elementary teachers' understanding of teaching science with the support of web-based portfolios. These two individuals were chosen because it was believed by the researcher that their representativeness would lead to main assertions about prospective teachers' understandings of teaching science. Both of the participants were traditional prospective elementary teachers (i.e., 22 years old, females with no science-specific background). In order to maintain the confidentiality of the participants, the pseudonyms Sarah and Jane were used in all aspects of this study.

Context

As described by the instructor of the course (Zembal-Saul, 2001) the participants in this study were members of a cohort of prospective elementary teachers engaged in a year-long internship program. The prospective teachers spent the entire year in one of four professional development schools (PDSs) that developed through an ongoing local school-university partnership. The web-based philosophy project was structured as an evidence-based argument about teaching and learning science that is developed over time. Prospective teachers generate a series of assertions or claims, support those claims with multiple pieces of evidence/artifacts (e.g., course projects, classroom observations), and justify evidence in light of the claims they make. Over the course of the semester, claims could be added, modified, or rejected on the basis of new evidence (Zembal-Saul, 2001). An example of the main page of the web-based portfolio is presented in Figure 1.



I. Espoused Platform for Science Learning & Teaching
  A. Version I
  B. Version I-Update
  C. Version II

II. Assignment Collection
  A. My Experiences as a Science Learner
  B. Science Talk – What do scientists do?
  C. Teaching Project
    1. Concept Interview
    2. Project Justification
    3. Analysis of Inquiry
    4. Lesson Plans
    5 The Five E Model

Figure 1. Sample of the main page of a web-based portfolio.

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Data Sources

Multiple sources of data were used in this study. The main source of data were the web-based portfolios that the participants developed during the Fall 2000 semester. More specifically, this study investigated three versions of the web-based science teaching philosophies that each of the participants developed as part of their web-based portfolios. Another source of data were the reflection statements developed by each of the participants. In their reflection statements, prospective teachers were asked to discuss what changes were made in the different versions of their philosophies and explain why. Specifically, participants were asked to reflect on how they saw their science teaching philosophies changing over time and to comment on the revisions they were making in each iteration (Zembal-Saul, 2001).

Data Analysis

Three analytic techniques were used to analyze the data: pattern-matching, explanation-building, and time-series analysis (Yin, 1984). A combination of these techniques was used in order to examine the progress of the two participants' understandings about learning to teach science, as it became evident from the nature of the three versions of their science teaching philosophies. Furthermore, a content analysis of the participants' reflective statements was done in order to illuminate their understandings of how their views of teaching and learning were changing over time.

In order to investigate how technology contributed to the task, the way participants made use of the multimedia possibilities of the web-based forum and the way they used hyperlinking were investigated. Specifically, the kinds of artifacts the participants used as evidence in the three versions of their philosophies and how they chose to link further information and artifacts within the text were examined. After the within-participant analysis was done, a cross-participant analysis followed in order to identify similarities and differences across the two participants.

Findings and Interpretations

Data from the three versions of the participants' science teaching philosophies and from their two reflection papers were analyzed in order to explore the nature of their philosophies, the ways that the web-based portfolio task supports thoughtful reflection and the ways technology contributes to this task. The findings are described based on the assertions that were made around three core areas: a) Insights into participants' thinking; b) Insights into context; and c) Insights into the task and particularly the role of technology.

Insights into participants' thinking

Overall, the claims that both of the participants developed, transformed from being generic in initial versions of their philosophies to being precise and science specific in the final versions. The claims that Sarah and Jane developed throughout the three versions of their philosophies are presented in Table 1. and Table 2. Both of the participants became more sensitive to children's thinking and learning and emphasized a student-centered approach, which became evident in their science teaching philosophies. Specifically, they seemed to be sensitive to the needs of children and to consider their preconceptions about science. As teachers, they recognized the need to design lessons based on their students' needs and interests and encourage them to express their ideas. This finding is significant because it stands in contrast to the literature that suggests that prospective teachers view themselves as the transmitters of knowledge to the children (e.g., Aguirre & Haggerty, 1995; Aguirre, Haggerty & Linder, 1990; Cohen, as cited in Prawat, 1992).

The nature of the claims that the participants developed in the initial versions of their philosophies supports the findings of previous studies that report beginning teachers tend to emphasize the physical engagement of children in activities. Particularly, both of the participants emphasized the fact that children learn through hands-on activities. According to Prawat (1992), this is firmed with a set of beliefs about teaching and learning, termed 'naïve constructivism'. As Prawat (1992) stated, beginning teachers have the notion that student interest and involvement (i.e., in 'hands-on activities') constitutes both a necessary and sufficient condition for worthwhile learning. However, this is just as problematic from a constructivist perspective: the tendency to equate activity with learning (Prawat, 1992). However, in the second and third versions of their philosophies, the participants of this study made the connection of physical engagement with more conceptual aspects of learning. Not only did the participants refer to 'minds-on' activities, but they also justified this statement. They explicitly stated that it is not enough to engage children in hands-on activities in order to support their learning. Recall that in the third version of her philosophy Maria stated:

> Hands-on/minds-on activities go a step beyond traditional hands-on activities, asking children to think about and explain science concepts. The focus is on what children are going to learn rather than what children are going to do. The activity moves beyond the realm of hands-on and requires students to apply their minds to the activity. (Maria, 3rd version)

In a similar way, Janice explained: "Students need to experience science concepts by using their senses to see first hand how science works. However, just the experiences aren't enough. Students also need to be able to think about the hows and whys of the science".

Table 1
Jane's claims across the three versions of her philosophy

Versions	Claims
V1	Children learn science by asking questions.
	Children learn science by relating it to the world outside through hands-on activities.
	Children learn science by being challenged to reflect deeply on science observations.
V2	Children learn science by asking questions.
	Children learn science by experiencing it through hands-on and minds-on activities.
	Children learn science by being able to reflect deeply on science observations.
	Teachers support science learning best when they ask questions to probe students' thinking as opposed to asking questions to elicit a certain answer.
V3	Same as Version 2.

Table 2
Sarah's claims across the three versions of her philosophy

Versions	Claims
V1	Children learn science through hands-on activities. Children learn science through inquiry-based investigations. Children learn science through activities that engage and challenge all learners. Teachers can support children's learning by modeling joy in science. Teachers can support children's learning by creating a safe and collaborative learning environment.
V2	Children learn science through hands-on and minds-on activities. Children learn science through inquiry-based investigations. Children learn through talking about science. Teachers can support children's learning by mediating their science experiences.
V3	Children learn science through hands-on and minds-on activities. Children learn science through inquiry-based investigations. Children learn best through talking about science. Children learn science through collaboration. Teachers can support children's learning by mediating their science experiences.

A pattern that was observed throughout the participants' web-based portfolios and particularly within their justification statements, was that they became more focused on the essential features of inquiry (National Research Council, 1996). The emphasis on teaching science as inquiry was evident in justification statements that emphasized question-driven investigations, the use of observational data, making connections between evidence and explanations and communicating these explanations to others. Inquiry into authentic questions generated from students' experiences is the central strategy for teaching science (National Research Council, 1996, p. 31). According to the *National Science Education Standards*, in inquiry, the focus is on children cooperatively investigating and developing an understanding of their world, and at the same time, learning about science as inquiry – procedures, scientific habits of mind, and significant knowledge of science content (National Research Council, 1996, p. 133). This finding is important because it reveals that the participants considered inquiry-based teaching, which reveals that their views were consisted with contemporary reform efforts in science education.

Insights into context

In addition to insights into prospective teachers' views, the web-based portfolios revealed the significance of the Professional Development Schools (PDSs) context and its impact on the participants' learning. Web-based portfolio served as a bridge between the university coursework and field experiences. It provided the vehicle for prospective elementary teachers to make connections between what they were learning in their science methods course and what they were applying in their practices.

As it became apparent through the participants' web-based philosophies, the greatest influence on their learning were the model lessons they experienced in the science methods course. In addition, moving from the first to the third versions of their philosophies, participants incorporated more evidence drawn out of their teaching experiences while they continued using evidence drawn from their science methods experiences. This suggests that the participants were making connections between university coursework and field experiences; that is, making connections between their experiences outside the classroom and their experiences in the classroom. This finding is significant, because as Putnam and Borko (2000) pointed out, "Teachers, both experienced and novice, often complain that learning experiences outside the classroom are too removed from the day-to-day work of teaching to have a meaningful impact" (p. 6). Thus, in the case of prospective teachers, it is important to combine their experiences in their methods courses with their field experiences. Such an approach can be enhanced through the Professional Development Schools (PDSs). Recently, PDSs have been recognized for their potential to provide unique opportunities to integrate university coursework and field experiences (Darling-Hammond, 1994, Levine & Trachtman, 1997, as cited in Zembal-Saul, 2001), bridging the theory - practice divide.

The role of the task and the technology

In this study, web-based portfolios provided a place where prospective teachers articulated their science teaching philosophies and presented them in a hypermedia format. In particular, web-based portfolios made participants' thinking visible and documented their growth. As Loughran and Corrigan (1995) noted, "A major focus of the process of developing a portfolio and the product is to help prospective teachers begin to articulate their understanding of what they think it means to be a teacher" (p. 17).

The findings of this study also are congruent with the literature that suggests that portfolio development may support reflection. The justification statements appeared to be a powerful technique for engaging prospective teachers in meaningful reflection since they required explicit and justified connections between the claims and evidence used to support them. According to Nettles and Petrick (1995), writing a rationale allows prospective teachers to reflect on their work, both in deciding for which outcome the artifact provides evidence and in realizing their proficiency in that particular teaching strategy or skill. In this study, web-based portfolios served as a vehicle for prospective teachers to reconsider and reevaluate their views of teaching and learning science in light of new learning experiences.

In addition, prospective teachers engaged in metacognitive activities while developing their philosophies. The development of a personal science teaching philosophy required them to think about their knowledge, understandings, ideas and beliefs about learning and teaching. Web-based portfolios provided the vehicle through which prospective teachers explored their understandings of learning to teach, through the development of different versions of their science teaching philosophies. According to Hoban (1997), prospective teachers should be encouraged to be metacognitive and become more aware of how they learn in teacher education courses with the intention of informing their decision-making as they construct their personal pedagogies.

Another important element of the task was the development of evidence-based claims by the prospective elementary teachers. Explanations and evidence are essential to our understanding and evaluation of claims (Brem & Ribs, 2000). However, several lines of research (e.g., Kuhn, 1991) have found that people have difficulties in making distinctions between and the respective roles of explanation and evidence in an argument. In this study, the web-based portfolio development engaged prospective elementary teachers in evidence-based claims construction, which proved to be to be a good strategy for supporting their ability to distinguish evidence and explanation. Having to craft justification statements, prospective elementary teachers had to explicitly distinguish between the claims they made, the evidence they used to support their claims and the explanation used to back up their evidence.

The web-based forum supported the engagement of prospective teachers in meaningful reflection since it allowed them to keep multiple versions of their philosophies. Thus, prospective teachers could look back to prior versions of their philosophies, build on their initial ideas, revise their views about teaching and learning science and easily reorganize their philosophies. Prospective teachers were able to view how their philosophies were changing over time, which supported a continuous engagement in metacognition, self-evaluation and self-reflection.

According to Morris and Buckland (2000), by compiling the portfolios in a web-based environment, prospective teachers are able to use the hyperlinking capabilities to organize the presentation in such a way that demonstrates their unique understanding of their own learning. Additionally, with the use of hyperlinking prospective teachers are able to reorganize their philosophies only by modifying some links.

The hypermedia component fosters connections between coursework, concepts, and applications because it allows the individual to designate links between ideas and themes (Morris & Buckland, 2000). The multimedia possibilities of the web-based portfolios allowed prospective elementary teachers to make nonlinear, dynamic representations of their science teaching philosophies. Through the hyperlinking process, prospective teachers made connections between their coursework and field experiences, between their claims, evidence and justification statements which resulted in an interconnected presentation of their learning experiences.

Another aspect of the web-based forum is its public nature since it makes the portfolio available to a variety of audiences. The web-based portfolio has the potential of being viewed by a greater number of people. Thus, greater effort and pride is taken to create a public document (Aschermann, 1999, p. 3). Moreover, the public nature of the web-based portfolios provides the opportunity for prospective teachers to give and receive feedback from peers or professors instantly. They are easier to share, making it possible for prospective teachers to see a variety of exemplars, view other perspectives of teaching and learning and challenge their own practices and beliefs (Morris & Buckland, 2000).

Conclusions

Given the findings of this study, it appears that the web-based philosophy task was conductive to making prospective elementary teachers' implicitly held personal pedagogical theories explicit and promoting their revision in light of new experiences and learning. In addition, the context appears to have supported the development of reform-oriented claims that emphasized children's thinking. Moreover, prospective teachers were able to conceptualize connections among what they were learning in class and what they were experiencing in schools. This type of integration has the potential to play a powerful role in increasing the robustness of emergent reform-oriented pedagogical theories and their influence on instruction. The next phase of our research will explore this potential.

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CURRICULUM BY DESIGN: IMPROVING STUDENT LEARNING IN COLLEGE CHEMISTRY AND BIOLOGY

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It is well documented that college students arrive poorly prepared to succeed in science and mathematics courses (Kean & Middlecamp, 1994). Reasons for this include: (a) lack of student conceptual understanding in science; (b) inability to think critically; (c) little interest in science; and (d) a lack of self-discipline and study skills. National attrition rates are high among first-year college students, particularly in underrepresented groups. Finally, college teaching is still heavily didactic in approach with little opportunities for active engagement necessary for students to construct their own conceptual understanding.

Purpose

The purpose of this paper is to demonstrate that if a Curriculum Design Model (CDM) is applied to course curriculum and instruction, then college students will be able to understand the basic concepts underlying important science topics. Further, the effectiveness of the Model can be tested in the form of improved student conceptual understanding, achievement and course retention. It is postulated that when students are given the opportunity to construct their own conceptual understanding, there is an increase in their motivation and interest in science.

Theoretical Background

Figure 1 illustrates the three tenets that underpin the Curriculum Design Model. These three tenets (less is more, scaffolding learning, scientific literacy) were derived from the professional experience of the faculty as well as a substantial research literature base.

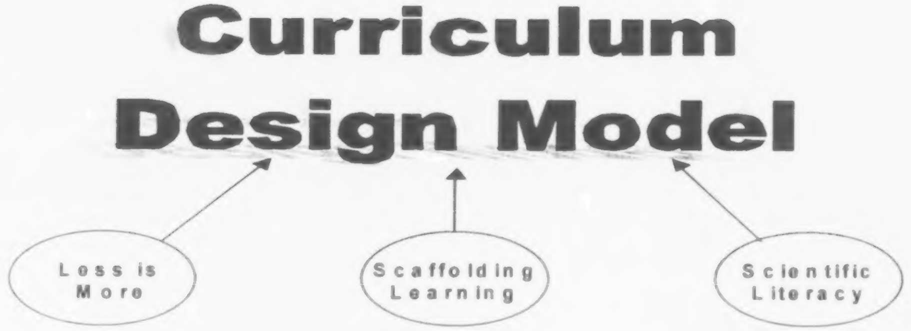

Figure 1. Three Tenets of the Curriculum Design Model.

Less is More: First Tenet of the Curriculum Design Model (CDM)

Recent research in college physics learning indicates that success in undergraduate courses depends heavily upon students following cookbook-like solutions to problem solving tasks (Maloney & Siegler, 1993). Further, success in these courses was not a valid indicator of student conceptual understanding (McDermott & Shaffer, 1992). Interviews with 'A' and 'B' students from these courses showed that many held naïve and incomplete views of basic science concepts. Findings from other studies concur that success in traditional undergraduate science courses is not a valid measure of the depth of their conceptual understanding (Maloney, 1994). Vosniadou (1996) suggested that core concepts within a discipline have a relational structure that directly affects conceptual understanding. The relatedness among these core concepts must be reflected in course curriculum and text-based materials. Similarly, Romance and Vitale (1997, 1999) suggested that instructional activities should be designed to require learners to demonstrate how they would represent their understanding of core concept relationships. Finally, the TIMSS study (Schmidt, McKnight & Raizen, 1996) found that instructional materials used in the United States typically consisted of many diffusely arranged concepts that inhibited meaningful learning. Further, the amount of information presented is so vast that it results in the mere "mentioning" of concepts rather than developing student understanding of core concepts and their relationships. This research base underpins the "less is more" tenet of the CDM. Instead of covering more topics, it is based on covering the most important topics in greater depth, and emphasizing relationships between core concepts.

Scaffolding Learning: Second Tenet of the CDM

Experts, unlike novices, are characterized by the degree to which they have developed and organized their conceptual understanding (e.g., Andersen, 1993; Carey, 1985; Chi, Glaser & Rees, 1982). Within this framework, the goal of meaningful learning is considered to be the continued organizational development of the conceptual understanding necessary for deep thought processing associated with abstractions and generalizations (Glaser, 1991; Glaser & Bassok, 1989; Royer, Cisero & Carlo, 1993). Reif and Heller (1982), in addressing problem-solving in physics, found that deep understanding involves hierarchical organization of conceptual knowledge into easily accessible schema. Carnine (1992), DeJong and Ferguson-Hessler (1996), & Grossen, et al., (1998), suggest that curriculum and instruction designed around 'big ideas' as core concepts promote active student conceptual understanding. Finally, Kozma et al., (1996), in studying learning in chemistry, have shown that novice learners cannot be expected to direct their attention to core concepts in a discipline. Rather, novices require extensive guidance from experts (teachers) to develop deep thought processing and conceptual understanding.

Supporting Scientific Literacy for All: Third Tenet of the CDM

Another fundamental issue associated with effective teaching and learning is the need for students to engage in meaningful discourse in order to construct their own conceptual understanding (Bleicher, 1998). Such discourse is promoted through collaborative learning environments where students feel comfortable to take risks, ask questions and share ideas. This is in keeping with the National Science Education Standard, "to advance learning and increase the scientific literacy of all students" (National Research Council, 1996).

Methodology

The research followed a mixed-method design (Frechtling & Sharp, 1997), involving both quantitative and qualitative research methodologies. It examined project activities and correlated these to changes in student learning, achievement, and interest in science. It also assessed changes in faculty understandings and practices in curriculum and instruction.

Student achievement data (exam scores, laboratory grades, final course grades) were collected. Survey data were collected from students, gathering feedback about all course components, but particularly the non-traditional recitations. The Reformed Teaching Observation Protocol (ACEPT, 2000), a cooperative learning classroom teaching rubric, was used to measure the effectiveness of the implementation of cooperative learning strategies by the undergraduate peer leaders who facilitate the non traditional recitations.

Data were analyzed using a strategy developed by Miles & Huberman (1994). This methodology provides a framework for a collaborative group of researchers to perform three research functions: (a) reduce the data to a subset of information (categories) without losing essential data; (b) display (matrices, maps, summaries) this information in a manner that facilitates group discussion and notation of consensus upon emerging patterns (narrative documents); and (c) draw conclusions that help explain observed participant actions and consequences.

Results

Example of A Module: Structure and Function of Cells

Most introductory biology students do not appreciate the significance of studying the cell because they do not have a conceptual framework within which to assimilate what they are being taught. To help develop such a framework, the cell is studied in lecture, laboratory and non-traditional recitation (Lifeline). By structuring the learning environment to provide reinforcement and application, a scaffold is created to promote student learning.

While the first two learning components (i.e., lecture and laboratory) are conceptually aligned, learning theory tells us that complex concepts are learned when students have opportunities to discuss and apply concepts leading to conceptual understanding. The non-traditional recitations provide a small-group, cooperative learning environment that supports student construction of their own understanding . Hence, given its pivotal role in the learning cycle, it is critical that these non-traditional learning experiences be well designed by applying a Curriculum Design Model that links conceptual learning in all three course components. By focusing their attention on the workings of the cell during lecture, visualizing different cell types in the laboratory, and engaging in meaningful discourse about the underlying concepts in the Lifeline sessions, the student learns about cell structure and function in three increasingly more focused instructional contexts. In doing so, multiple instructional activities are provided for learners to construct meaningful understanding. Using multiple pathways to enhance student understanding is an important cognitive strategy as it provides a well designed vehicle to reinforce and clarify student understanding and misconceptions (Bleicher, et al., 2001). Learning of complex concepts requires multiple instructional interventions with the same or similar concepts in order to provide opportunities for learners to construct their own understanding (Bleicher & Romance, 2001).

Student Performance

Students expressed more confidence in their ability to reason-through and solve chemistry and biology problems. Over 70% of students indicated that the non traditional recitations were helpful to their success in the course.

To assess the impact of the CDM on student performance, the grade distribution for the course taught in the current year was compared with those of the previous three years. These data show a 20% reduction in the percentage of students receiving D's, F's, or withdrawing from the course. Withdrawals alone dropped to 5% this year compared to over 22% previously.

Implications for College Science Teaching

Building a Professional Learning Community among college professors is a challenging endeavor. Faculty had a common purpose and were willing to invest time and energy in addressing the complex issues and changes which needed to be made. Faculty were willing to put aside their prior conceptions and become more open to each other's ideas and to those ideas suggested in current research journals in order to expand their own understanding of the problems. In the process of meeting for the past several years, faculty participated in conversation following presentations by distinguished science and science education researchers studying teaching and learning. While much of this early collaborative work was initially spearheaded by efforts of the science education faculty, the scope of the work has become a shared partnership best described as a Professional Learning Community. Even with a positive working relationship within and outside each college, faculty needed to establish an action plan so as to clarify goals and objectives, identify tasks and responsibilities and plan for resulting evaluation of activities.

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NOVICE TEACHERS' PERCEPTIONS OF A MULTIFACETED MENTORING PROGRAM AND THE NEEDS OF EARLY-CAREER SCIENCE TEACHERS

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My first year of K-12 teaching began with the principal taking me to my room and wishing me luck. The atmosphere in that small, rural school was not very welcoming nor was it supportive. The school had experienced a high turnover in many positions but the teachers in the remaining positions had been in the community and school for many years thus there were few mid-career teachers. The experienced teachers seemed to view the new teachers with suspicion. It was a "sink or swim" proposition. I found a different position after one year. My position was filled by a succession of first year teachers during the next few years. I am certain most would agree with me that it would have been beneficial to have had a mentor. A colleague mentioned that teaching might be the only profession in which the newest employee is given the most uncomfortable chair, the broken stapler, and the most difficult assignment.

It has long been recognized that teachers need more-more support, more resources and a more supportive environment (Breeding & Whitworth, 1999; Fuller & Brown, 1975; Hirst, 2000; Prosise & Heller, 1993). Research has identified a number of recurring needs common to many new teachers, such as the need for better classroom management skills, better understanding of the workings of the specific building, and help in communicating with parents (Fuller & Brown, 1975; Hirst, 2000). Teachers in science and mathematics may have additional problems such as understanding content, obtaining and preparing laboratory materials, or helping students understand particularly difficult material. But new teachers are not the only ones needing support and assistance. Mentors need help in knowing how best to mentor and administrators need to know how to support. Providing resources for mentors and administrators can improve the induction program and thus the experience of the novice teacher (Brock & Grady, 1997).

Supporting new teachers can improve student performance, teacher success, morale, and retention (Hirst, 2000; Million, 1988; Prosise & Heller, 1993). This can be particularly important in areas such as science and mathematics where nationwide teacher shortages are common (Shortage of teachers to grow, 1998).

Within the last decade the sate of Michigan began addressing these needs and requiring that new, probationary teachers receive mentoring (Hirst, 2000). Although Michigan legislation was passed several years ago (Pa 335, 1993 & PA 289, 2996), our experience shows that many rural, Upper Peninsula schools have been slow to establish programs to support new teachers. Out of concern for new teachers, the Upper Peninsula Center for Educational Development and the Glenn T. Seaborg Center for Teaching and Learning Science and Mathematics, both of Northern Michigan University, coincidentally proposed and received grants to provide frameworks for support during the induction years of new teachers. Upon discovering that the goals were similar, the two centers administering the Upper Peninsula Mentoring Project and the Seaborg Academy began collaborating and a program was designed.

Schools in the Upper Peninsula of Michigan have some special problems associated with providing professional development and support for teachers. Many of the schools are small and rural. Some of our new teachers had a different prep each hour and, in some cases, one teacher comprises the entire science department of a school. Weather in the winter often results in hazardous travel, making it difficult for teachers to travel to us for support. Finally, a shrinking student population in many areas results in districts offering experienced teachers retirement buy-outs, leaving a larger cadre of inexperienced teachers in the wake.

During the first year of the program, presenters from the sponsoring programs, the Upper Peninsula Center for Educational Development and the Seaborg Center, traveled to three different sites in the Upper Peninsula, seven times throughout the year, to meet with new teachers and their mentors. The needs of both new teachers and mentors were continuously monitored and consequently the delivery of the program was adjusted accordingly. Science and mathematics teachers met separately with the faculty and administration of the Seaborg Center and received special support and assistance from them.

During the second year, first year teachers and mentors received approximately the same support as those participating during the first year. Second year science and mathematics teachers had a different set of options. One of those was a graduate course in the Effective Teaching of Science delivered by distance learning during the fall semester. During the winter semester, two courses, Motivation and Management in the Science Classroom, and Motivation and Learning in the Mathematics Classroom, were combined in a web-based classroom.

While research indicates that new teachers have several needs, experienced teachers and novice teachers may have differing views of the importance of these needs. In addition, needs may vary due to changes in society (e.g., the need for distance learning options), special geographic needs (e.g., isolated rural schools) or small school issues (e.g., the new teacher is the only science teacher in the school). This study is an analysis of information gathered during and following the first year of a mentoring program to determine how early-career teachers perceive the mentoring process and its outcomes. We report on the successes and weaknesses of the program and make recommendations for future mentoring support programs.

Design and Approach of the Program

The mentoring program was designed to provide support to three different groups; novice teachers, experienced teacher mentors, and administrators. In the fall, prior to the first day of school, we met for an early-morning meeting with administrators, including principals and superintendents. This was followed by an all-day introductory meeting with new teachers and their mentors, as well as the administrators. During the year we met seven times with each of the groups of teachers. All participants were provided with loose-leaf notebooks of information.

Administrators

The administrators were provided with information about the state requirements for mentoring novice teachers as well as the more extensive requirements for professional development. They were also informed about research into the needs of new teachers and provided with suggestions concerning how they could better support both the mentor and his/her protégé. Following this meeting, the new teachers arrived with their mentors and were given the opportunity to interact with the administrators.

Mentors

Mentors were given much information about the needs of novice teachers and how they could supply support in meaningful ways. They were trained about how to observe in a classroom and ways to give feedback without taking on the role as an evaluator. We also provided them with information concerning how best to work with adult learners. Mentors were offered the opportunity to obtain graduate credit by completing a project along with their mentoring experience. Many chose to create handbooks for new teachers in their buildings.

Novice Teachers

Topics for novice teachers included many of the topics research has identified as particular problems for new teachers. Sessions were provided on management, assessment (including state-wide mandated testing), addressing the needs of special education students, and legal issues for teachers. Teachers were provided with copies of *The First Days of School* (Wong & Wong, 1991) along with many valuable resources for their loose-leaf notebooks.

Special Help for Science Teachers

We provided dinner for the attendees each meeting as well as time for the mentors and novice teachers to spend some time planning and working together. During dinner, members of the Seaborg Center for Teaching and Learning Science and Mathematics sat with the science and mathematics teachers and their mentors, providing additional help specific to their subject areas. We provided them with registration to the Seaborg Center Fall Conference, a regional conference for science and mathematics teachers. It was also possible to get to know these new teachers quite well during the meetings. During the second year, first year participants were provided with special invitations to participate in the distance-education graduate courses mentioned above and some financial support was provided.

Initial Indictors of Effectiveness

Participants were asked to respond to evaluations at each session as well as a more extensive evaluation at the end. In addition, we are currently interviewing science teachers to determine in what particular ways the program was or was not helpful. While all the data is not in, initial surveys indicated that many aspects of the mentoring program were found to be helpful to both the novice and her mentor.

What Worked

Almost all of the novice teachers indicated that the materials we provided were of immense help to them. Comments indicated that the new teachers referred to the materials often during their first year. The only comment made that was somewhat negative was that some of the teachers wished they had been able to use all the materials from the first. During the second year we complied by giving them all the materials in the beginning.

Both the mentors and the new teachers greatly valued the time spent together and some commented that they did not want the groups to be split apart as often. Many indicated that they did not feel they had sufficient time during the school week to work together as a mentor/mentee team and that this time together was very valuable.

All of the sessions offered were found to be very helpful to the novice teachers. However, it should be noted that mentors did not find all sessions as helpful, perhaps understandably. On the other hand, mentors indicated that they felt that the program greatly enhanced their ability to be effective and supportive. Some even indicated that they had no idea prior to the program the extent or importance of the role of mentor.

Participant Reservations

While the overall assessment of the program by the teachers was quite positive, some specific comments were made by a number of teachers and these are being addressed during the second year. Some of the teachers, particularly new teachers, felt that the time of day (immediately after school) did not give them enough time to recover from they day. They felt that they were so fatigued that they could not "get as much out of it" as they would have liked. Along with this, it was felt that five meetings (the introductory meeting followed by two additional meetings each semester) would be sufficient. We are trying this approach during the second year of the program.

Another comment made frequently by both the novice teacher and the mentor was that they wanted more time together and less time in separate sessions. As mentioned above, teachers felt that administration did not provide sufficient time or support for the teachers to spend time working together during the school day and this time was invaluable to them.

Probably one of the most difficult problems to manage was that of "new teachers" who came to the program with many years of experience. At least one science teacher had over twenty years of teaching experience. Unfortunately, this teacher, while new to the district, did not feel that the program was appropriate for her and we would have to concur. Her needs were very different from those of a first-year teacher.

In Conclusion: Some Suggestions

Particularly in science, teacher retention is a very real problem. Providing support for new teachers could potentially increase the number of teachers who remain in the field. Administrators should be encouraged to provide whatever support they can to both the new teacher and the mentor. The administrator should choose mentors carefully and the mentors should be willing to take this role seriously. Both novice teachers and their mentors should be given ample time to interact, visit one another's classroom, and give and receive feedback. Also, administrators need to realize that the needs of the new-to-the-district but experienced teacher are very different from those of a first- or second-year teacher and appropriate support should be given.

Since rural teachers may not have a mentor in the same subject area, a network of teachers in the region can be provided electronically which would serve as support for teachers in isolated areas. This is one of the directions we are planning to take with the next phase of the program.

We found that mentors needed and wanted the support of a training program on how to be a mentor. In addition the training and materials we provided both the mentors and the novice teachers were found to be of great value. Well-organized reference materials and tips were used often by the new teachers and planning sheets provided to the mentor-novice teams were used by most.

Probably the most successful aspect of the program was simply providing the time and support for the mentors and new teachers to interact with each other and with others in the same situations, as well as university-level educators. As the teams took the time to plan, work and reflect together, relationships were built and nurtured, and teachers indicated that they felt more competent and confident.

The second-year graduate courses provided via the Internet and Interactive Television are proving to be extremely popular with the newer teacher. Initial reports of the data indicate that the participants found these courses to positively impact their classrooms and themselves. It is hoped that, with continued support, we can increase both retention and effectiveness of the teachers of science in the Upper Peninsula of Michigan.

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PROFESSIONAL DEVELOPMENT FOR ELEMENTARY SCIENCE TEACHERS: IMPLICATIONS FOR PRACTICE

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The dawn of a new century has brought many challenges to our nation's schools. Ever higher standards, calls for greater accountability, a growing diversity among the student body, and explosive growth in information and technology are among many of the issues schools must successfully address in the coming years. So swiftly are these challenges arising that is it is becoming ever more difficult for the classroom teacher to keep his/her professional skills sharpened for the tasks demanded of today's, and tomorrow's, teachers.

Perhaps the greatest challenge facing our schools in this new century will be to maintain a teaching force that is knowledgeable and skilled at meeting the current and future needs of our students and our society. Nowhere is this more important than in science instruction. The scientific advances being made almost daily, and their impact on the quality of our life, bring into sharp focus the critical need for our future citizens to be well-grounded in scientific concepts and knowledge. This highlights the need for our students to have quality science instruction from well-prepared and well-qualified teachers.

The media has focused considerable attention on the shortage of secondary science teachers. However, just as critical is the inadequacy of science instruction in the elementary school. If students are to have an adequate foundation for science instruction at the secondary level that foundation must be laid in the elementary grades. Yet, many elementary teachers are ill-equipped for this task.

The Inadequacy of Elementary Science Instruction

Weiss (1987) found that only 31% of kindergarten to third grade teachers and 42% of fourth through sixth grade teachers had taken a science course. In addition, he found that fewer than half the states require elementary teachers to take a course in science methods. Many elementary teachers, therefore, complete their preservice preparation without knowledge or skills in the preparation, presentation, and application of science concepts in their classrooms. Wiess also reported that 82% of elementary teachers surveyed felt qualified to teach reading, while only 27% felt competent to teach life science and only 15% felt prepared to teach physical or earth/space science.

The inquiry method, which promotes critical thinking and problem solving skills, has been identified as an effective approach to quality science instruction (National Science Foundation, 1998; Rhoton, 1992). However, many elementary school teachers do not understand science content or methods well enough to utilize the inquiry approach in their teaching. According to Loucks-Horsley, Kaptian, Carlson, Kuerbis, Clark, Nelle, Sasche, and Walton (1990) elementary teachers encounter a number of obstacles to teaching science effectively through inquiry.

1. There is a lack of preparation in science for elementary teachers. The inquiry approach to teaching science requires an in-depth knowledge of the content to facilitate guiding students in active scientific inquiry. The National Science Teachers Association (NSTA), for instance, recommends one course each in biology, physics, and earth science for elementary science teachers.

2. The emphasis in the preparation of elementary teachers is on language and math and not science. In general, elementary teachers receive minimal exposure to science in their preservice preparation.

3. Insufficient time is often given to the teaching of science in elementary schools. The inquiry approach requires significant planning time for the science curriculum to be coherent and comprehensive. It also requires sufficient time in class to stimulate critical thinking and inquiry. The NSTA recommends that the minimal amount of time spent per week in science should be 2 1/2 hours in primary grades and 4 hours in upper grades. It is possible to integrate science with other disciplines, thus increasing the time spent on instruction. However, care must be taken to insure that science is not diminished when it is integrated with other subjects (Louckes-Horsley et. al, 1989).

4. There are an inadequate number of well-defined elementary science programs. Few school districts coordinate science goals, materials, and staff development offerings.

5. There is a shortage of adequate support materials for instruction. However, the relationship between the level of resources and educational quality is less important than how the available resources are used.

6. There is a lack of professional development for elementary teachers. Concurrent with limited understanding of science content on the part of elementary teachers is a limited ability to apply or use higher level reasoning in understanding science concepts, such as the utilization of controlling variables.

Professional Development in Elementary Science Instruction

Overcoming these obstacles will not be easy. A focused and concerted effort must be made to improve the ability of elementary teachers to provide quality science instruction. This will require a developmentally sequenced plan that provides pervasive reform, from preservice through inservice. Louckes-Horsley et. al. (1988; 1990) have proposed a three-stage plan for achieving this.

1. The early phase is in the university. Preservice preparation should combine an understanding of how children learn and hands-on experience in working with students in science.

2. The middle phase emphasizes teaching, the integration and application of the teacher's preparation. A new teacher should have a lighter work load and ample time to facilitate this process for the first two years of teaching.

3. The later phase involves improving and expanding teachers' skills in teaching science--allowing time to work together and observe each other. Finding adequate planning time is often the biggest obstacle to overcome. Principals need to work creatively with their faculty to support them in this area. O'Brien (1997) suggests a mix of personal time and release time to establish on-going networking for elementary science.

Networking with other teachers can also foster the implementation of inquiry by observing other teachers or having teacher coaches assist them (National Science Foundation, 1998; Luft, 1999). Teachers change grades and new teachers are hired. When teachers do change grade levels there is no guarantee that their preparation will be sufficient for their new assignment. The National Science Foundation (1998) proposes that mentor teachers be assigned to new teachers to provide support and assistance in successfully implementing the inquiry approach to science instruction.

Providing Effective Professional Development

It is obvious that a key factor in meeting the challenge of quality science instruction in the elementary school will be a well-designed, flexible and effective system of ongoing professional development. And, yet, for the most part, professional development for educators has a somewhat spotty and inconsistent record of success. McRobbie (2000) notes that well over half of U.S. teachers get less than a day's worth of professional development annually, in contrast to teachers in other countries who engage in professional development for 10-20 hours a week. Hilliard (1997), in claiming that a critical problem exists with traditional professional development activities, calls for fundamental change in how such activities are implemented.

The traditional method of providing professional development to teachers is the one-shot workshop squeezed in among a myriad of other activities during a teacher "work day." In our fast-paced, hurry-up world even providing this amount and type of training can be a challenge. Yet, a recent report by the U.S. Department of Education (2000) noted that eight hours is the threshold teachers say is critical for them to gain any value from a professional development activity.

Newman and King (2000) observed that conventional professional development has failed to improve teaching because it does not meet several key conditions for teacher learning. These conditions include:

1. Giving teachers sustained opportunities to study, experiment with, and receive advice on innovations. Most professional development activities involve brief workshops or conferences with no provision for follow-up or feedback.

2. Providing opportunities for teachers to collaborate with professional peers or to gain expertise through access to external researchers or program developers. Materials and programs

are usually presented by experts, but these resources are not integrated into existing systems of peer collaboration.

3. Giving teachers influence over the substance and process of professional development. Most professional development activities are dictated by local or state officials with little teacher input.

Newman and King concluded that teacher success in improving student achievement is dependent on teachers being able to implement knowledge and skills they have gained in a particular school and in a particular context. This was echoed to a certain extent by Guskey and Sparks (1996) who described a model for professional development based on the assumption that professional development is influenced by a number of factors including content characteristics, process variables, and context characteristics.

A number of writers have explored factors that can lead to effective professional development for teachers (Pennell & Firestone, 1998; Fitzsimmons & Kerpelman, 1994; Webb, 1996; and Sparks & Hirsh, 1997). Successful alternatives to conventional professional development were identified by McKenna (1998) as being job-embedded, mentor-dependent learning modes such as action research, small group problem-solving, and peer observation.

Ronnerman (1996) suggested letting teachers control their own professional development and allowing the problem, not the method, to guide teacher development. This is similar to a professional development program described by Crowther (1998) that has four components: clear expectations, focus on results, effective support systems, and good modeling. Crowther reported success by utilizing such practices as self-assessment, site-based decision-making, a focus on curriculum, and study groups.

A Project to Improve Elementary Science Instruction

Purpose and Description

This project's goal was to design a professional development model to improve the skills of elementary teachers in providing quality science instruction. Surveys have concluded that lack of training, time, and instructional materials are obstacles for elementary science teachers (Weiss, 1987). This project's goal was to address those critical elements.

Eight elementary schools in a mid-sized west central Texas school district were selected for the project. These eight schools have a student of color population of 40% or greater and the average pass rate on the reading section of the Texas Academic Assessment of Skills test was 10 percentage points lower than the district average. Our preliminary survey of elementary teachers in this district identified the following needs for improving their ability to provide quality instruction in science: (a) interaction with the science consultant and other resource personnel to enhance their instruction; (b) increased science preparation to enhance their confidence as science teachers; (c) additional activities that correlate to the content area using inexpensive materials.

To meet these needs, we conducted a Summer Institute and follow-up meetings during the succeeding academic year. These activities provided:

1. a deeper and practical understanding of, and skill at, application of the scientific method in life-science problem solving;

2. "hands-on" application of methods, including time to assemble the needed supplies;

3. increased knowledge of specific life science content;

4. opportunities for the teachers to develop a shared vision of the goals and science vocabulary for each grade level (vertical alignment awareness);

5. equipment (including a digital camera and color computer printer for each participating campus); and,

6. reading resources and manipulatives and materials for classroom science activities.

The Summer Institute focused on content mastery and application. Several guest speakers were utilized and teachers had opportunities for hands-on learning in how to teach science concepts.

Throughout the academic year project staff met with participating teachers at different school campuses. This promoted sharing in many areas, such as how labs were conducted, how to store and share equipment, how to implement the activities learned in the summer, how to schedule time for special interest clubs (such as a science club), and how to find financial resources for equipment. Project staff also shared innovative ways of utilizing technology for teaching science.

The Evaluation Process

A variety of sources and procedures were used to collect evaluation data for this project. For each of the topics addressed during the Summer Institute pretests and post tests were administered to the participants at the beginning and ending of each session. These tests addressed the content to be covered during that particular session. The differences in the pre- and post tests measured the increase in participants' knowledge of science content as a result of each session.

Also, at the end of each session participants were asked to complete a questionnaire regarding their perceptions of the effectiveness of that particular session. This instrument dealt with the quality of the presentation, of instructional materials, session format, etc. Instrument items were arranged in a Likert-type format and included some open-ended questions as well.

Approximately two weeks after the conclusion of the three-week Summer Institute structured interviews were held with participants. Questions were posed to elicit both knowledge of content and how the content would be integrated into the classroom. Although specific questions were developed for the structured interview, evaluators also asked follow-up questions based on participants' responses.

During the school year teachers were observed in their classrooms to determine to what extent they were integrating the information and skills addressed in the Summer Institute and in the Saturday sessions conducted during the academic year. A modified rubric developed for this purpose was used to collect information during the observation.

Two final avenues were used to collect data. Approximately six months after the conclusion of the Summer Institute questionnaires were sent to teachers who were project participants and to their principals. The teachers' instrument was designed to determine teachers' perception of how useful they felt the information, training and support provided by the project was over time and to determine how much, if any, of the information and skills addressed in the project they were integrating into their teaching of science.

At the same time principals at participants' schools were sent an evaluation instrument, as well. The principals' instrument addressed their perceptions of any changes in the quality of the teachers' science teaching as a result of their participation in the project. Principals were asked to report their perceptions based upon their own observations of the teachers.

Evaluation Results

As illustrated by Table 1, pre- and post test results on content knowledge showed a substantial growth, in general, in teachers' knowledge of science content. Gains ranged from 78 points (out of 100) on the Immune System to 20 points on Rubrics. The smallest gains in knowledge were in what might be called a "pedagogical area" (rubrics), a reflection possibly of the fact that participants were already fairly familiar with the content in that area. The low pretest scores on science content indicated participants' apparent lack of initial understanding of the science content covered by the Institute. The relatively high post test scores, though, demonstrate an impressive gain of the participants' short-term understanding of science content as a result of Institute sessions.

The perceived effectiveness of the sessions were also quite high. As can be seen in Table 2, overall the Summer Institute sessions were rated as "highly effective" with the highest rating on the organization of the sessions and the lowest on the pace of the sessions. In regard to individual Institute sessions, ratings were fairly high as well, as can be seen in Table 3. The sessions on Rubrics and on Immunology were rated particularly high. Perceived as less effective were the sessions on the cellular process and the heart. Since these were presented by guest lecturers, participants' responses may be more a reflection of the presenters than the session content.

Table 1

Content Knowledge Pretest and Post Test Averages

Session	Avg. Pretest Score	Avg. Post-Test Score
Cellular Processes	45	88
Exercise Physiology	42	85
The Heart	51	93
Immune System	11	89
Processing Skills	21	70
Rubrics	71	91

Table 2

Perceived Effectiveness of Summer Institute
("1" - Strongly Agree with the statement, "5" - Strongly Disagree with the statement)

Statement	Average Rating
1. The summer institute was well-organized.	2.1
2. The various presentations were scheduled in the appropriate sequence.	2.1
3. Presentations were paced appropriately (enough time was spent to cover the topic, but the pace was fast enough to maintain interest).	3.0
4. There was an effective mix of lecture, discussion, hands-on, and other types of activities.	2.1
5. Content presented was relevant and useful to me in my current position.	2.6

Table 3

Participants' Perceived Effectiveness of Individual Sessions of Summer Institute

Session	Statement	1	2	3	4	5	6	7	8
Rubrics		4.7	4.8	4.8	4.8	4.7	4.9	4.3	4.9
Immune System		4.3	4.3	4.0	4.0	4.3	4.3	4.3	4.0
Immunology		4.6	5.0	5.0	5.0	4.8	4.9	4.9	5.0
The Heart		3.9	3.6	3.6	3.6	4.1	4.1	3.7	3.4
Processing Skills		4.4	4.3	4.4	4.4	4.6	4.6	4.5	4.6
Pets		4.1	4.8	4.8	4.8	4.6	4.8	4.8	4.2
Exercise Physiology		4.6	4.7	4.3	4.6	3.9	4.5	4.5	4.8
Cellular Processes		3.9	4.0	3.9	3.8	4.7	4.2	4.0	3.5

To obtain more insight into the participants' reasoning in regard to their ratings two open-ended questions were also posed:

1. Which part of the presentation was most beneficial to you?
2. What would you change to make the presentation more effective?

Participants' responses to these two questions have been summarized in Table 4. As can be seen in this Table, for several of the sessions criticisms were given on the level of difficulty of the material with many teachers claiming it was too complex for them to adequately grasp and presented too quickly for them to absorb. There were also negative reactions to the format of the sessions. Teachers indicated a strong preference for activities that were more concrete and that involved their active participation.

Table 4

Participants' Responses to Open-Ended Questions

Please respond in more detail to any of the items above that would assist us in better understanding and interpreting your response.

Some of the things discussed are way over 4th graders' heads. The information needs to be geared way down so kids could understand better and I could teach the concepts better. I really like the books with the teachers guides and the AIM's activities.

More activities teaching us how to teach would have been great.

I think too much was covered in too little time.

A lot of the material is far too complex to teach in elementary school.

Some of the activities, information, etc. was on a much higher education level than what we teach but much of this was too advanced.

The information was good but it was too in depth. This material was too much to be taught at my particular grade level.

There needs to be more activities based for immediate use in the classroom.

If this class was related to my grade level. I can only use a few materials in my room.

I wish we could have done more "lesson type" things for lower grade levels. I really thought this was going to be an extended workshop type class. I didn't realize it would be so many tests and involve so much college level discussing.

Any suggestions for future Summer Institutes?

Don't make this session a "Class," make it more informational for each grade level.

I feel that more time is needed on actually developing plans for the classroom use.

Implementation plans need to be made. More grade level material is needed.

The information presented was valuable (if I were studying to be scientist). However, as an elementary teacher the information was much too detailed and high level. The information we were required to know for testing purposes was so intense, that the focus soon turned to only wanting to learn what I had to.

Material presented at times was fast paced. I needed more time to take in certain terms, especially those I had not heard since high school biology or college classes.

More hands on and sharing of lessons and materials to use in the classroom.

Opportunities to try out some more of the ideas would have been helpful.

More visuals, slower pace, information that is keyed lower towards the grade level that we are teaching. We felt that most of the information was over our heads and should have been modified for our classrooms. The vocabulary was hard and students will never understand it in these terms. We have little use for DNA, genes and etc. below 5th grade.

I really enjoyed this institute, even thought it was hard for me to study for tests again. I will use the information in my classroom, and I look forward to utilizing the materials.

More practical, hands-on activities for younger elementary school students.

Put the information into layman's terms so that we can teach it to students in K,1,2....

Approximately two weeks after the Summer Institute, structured interviews were held with project participants. Two groups were formed from the participants and a session conducted with each group. These sessions were intended to collect information regarding how well participants appeared to understand the information covered in the Institute and how well they might be able to integrate the content in their classrooms.

While one evaluator asked each question, another evaluator rated participants' responses using a rubric that rated responses based on five dimensions: Content, Terminology, Application, Clarity, and Integration. For each dimension the evaluator rated overall group responses from 0-2, (0-did not address, 1-addressed to some extent, 2-addressed to a great extent.) Table 5 displays the results of structured interviews held with project participants.

Table 5

Evaluator's Ratings of Participants' Responses to Interview Questions

	Content		Terminology		Application		Clarity		Integration	
Question	I	II	I	II	I	II	I	II	I	II
1	2	1	2	1	2	2	2	2	2	2
2	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	2	2	2	2	1	2
4	2	1	2	1	2	2	2	1	2	2
5	1	1	1	1	2	1	2	1	2	1
6	2	0	1	1	2	1	2	1	2	1
7	1	1	1	1	2	1	1	1	1	1
8	1	2	1	1	2	2	2	1	2	2
9	1	2	1	2	1	2	1	2	1	2
10	0	0	0	0	1	1	1	1	1	1

Comments:
GROUP I
Break down into grade levels, some things not appropriate for some grades
More activities and resources, Provide information on developing learning centers
Much of the content at too high a level, More application
GROUP II
Loved the brain and heart presentations, Loved part with the dog, Very hard work!

As can be seen in this Table, teachers appeared to be fairly adept at understanding and using the content and methodology addressed in the Summer Institute. Participants were familiar with the terminology, how to apply it to the classroom and integrate it into the curriculum, although they felt more comfortable with some of the content areas than with others. Comments again echoed those expressed on other evaluation instruments regarding the level and expectations of the content.

To evaluate how well participants integrated science content and methodology in their classrooms observations were conducted with selected project participants. The rubric designed for this purpose addressed both the content and teaching methodology addressed in the Summer Institute and rated teachers on both a qualitative (Q1) and a quantitative (Q2) scale. The results of these observations can be seen in Table 6. As indicated in this Table, teachers appeared to be utilizing appropriate teaching methodology, but there was little evidence that they were actively implementing and integrating science content from the Summer Institute in their classrooms.

Approximately six months after the beginning of the school year all participants were sent an instrument designed to collect information regarding participants' perceptions of the effectiveness of the project and the extent to which project activities had impacted classroom practice. Participants indicated that they were using the information on content, methodology and resources they had obtained through project activities. They also appeared to be much more comfortable with science content and more knowledgeable about how to teach it.

Responses to this instrument also indicated that respondents were participating in follow-up project activities and that they appreciated the opportunity to continue those activities and to interact with their colleagues. Their understanding and use of resources related to teaching science appears to have increased as a result of the project, and they indicated a comfort level with having resources and support available to them.

Table 6

In-Class Observations of Selected Project Participants

Observation 1

Rubrics: Q1-5 Q2-5
Children engaged in activity, although some not fully

Processing Skills: Q1-5 Q2-5
All children actively engaged at a fairly high level in cooperative learning

Observation 2

Rubrics: Q1-4 Q2-4
Children actively engaged

Processing Skills: Q1-4 Q2-5
Children were assigned a project presentation on a particular type of whale. Each child had a designated role on the project. When the project was complete and had been presented, children graded themselves on a rubric, as well as grading other students.

Observation 3

Rubrics: Q1-5 Q2-5
Children worked very well together to complete the project

Processing Skills: Q1-5 Q2-5
Used data collection, defining, predicting. The project involved properties of water and was very well-organized

Observation 4

Cooperative Learning: Q1-5 Q2-5
Students engaged in learning about cooperative learning and processing skills. The teacher assigned each student a specific duty on the project and they carried it out in an appropriate manner.

Processing Skills: Q1-5 Q2-5
The teacher set up centers designed to have the children infer, define operational, collect data, and predict. Excellent activity.

Discussion

The results of this evaluation process reveal a number of insights into effective professional development for teachers, particularly in regard to improving science instruction. Teachers appeared to substantially increase their knowledge of science content, particularly in those areas addressed by the Summer Institute. Despite their recurring complaints that the content was too difficult for the students they taught, teachers did feel more comfortable with the terminology and concepts of the science content after the Institute. This increased knowledge and comfort level contributed to teachers' improved ability to teach science to their students. This suggests that a focus on increasing knowledge and understanding of content, while uncomfortable, is translated into improved instruction in the classroom.

Participants indicated a strong preference for hands-on, practical type activities that they could immediately pick up and use in their classrooms. We also found that teachers used some of the techniques and strategies they had learned in regard to teaching science, but they tended not to use those that did not fit in with their particular teaching style or preference. Also, the longer teachers waited to use techniques and strategies the less likely they were to use them at all. In fact, without a specific plan to incorporate skills used during the Summer Institute some teachers failed to make significant changes in the way they taught science.

Implications for the Professional Development of Science Teachers

Our experience and study indicates that effective professional development activities for teachers include one or more of the following key characteristics: (a) planning that includes input from teachers, principals and other district personnel; (b) time with other teachers; (c) a combination of content and process topics; (d) a specific implementation goal; and (e) strengthened connections between teachers and a broad variety of instructional and community resources. Each of these key characteristics are described below.

Planning that Includes Input from Teachers, Principals and Other District Personnel

Classroom teachers have the most direct knowledge of their needs as teachers and of the needs of their students. Therefore, planning for professional development activities should include input from teachers to insure relevance of topics and a sense of ownership among the teachers (King, 2000). Professional development activity planning that includes significant teacher input will be more likely to produce activities that address the identified needs of teachers (Ramey-Gassert, 1997). During the design phase our project included input from the developers of state curriculum standards, district and educational service center curriculum specialists, and from classroom teachers.

Soliciting input from principals allowed proper consideration of teacher schedules and campus-wide needs that participants could address after the development activities. Input from district personnel allowed the development of activities to address existing problems and to prepare teachers for district-wide curriculum initiatives (National Science Foundation, 1998). Finally, as Allen (1998) noted, and as we also found, active support by principals and district administrators is critical to the success of any change effort.

Time with Other Teachers

Through both observation and participant feedback, we noted that activities designed to increase the amount of time teachers spend with other teachers supports innovation through (a) the sharing of practical means to implement good ideas, (b) development of formal/informal peer support structures which facilitate guided risk-taking, (c) vertical alignment of content topics and pedagogy, (d) increased sharing of development opportunities gained through workshops or grant activities experienced by part of a campus faculty and (e) renewal of the teacher's motivation for and interest in innovative teaching. Teachers who are considering innovation should be allowed time with other teachers who are experimenting (Hoewisch, 1998), or, more importantly, with teachers who have succeeded in classroom innovation (King, 2000).

Our experience suggests that effective professional development activities should include some unstructured time to allow teachers to raise questions about specific issues they are facing (National Science Foundation, 1998). Several sources cited the willingness of professional development instructors to adapt activities to address the current learning and situation of teachers (Dana, 1997; National Science Foundation, 1998). We found that meeting in the teachers' classrooms facilitated sharing among teachers and supported each of the key characteristics discussed here.

A Combination of Content and Process Topics

Both content and effective pedagogy are required for a teacher to effectively implement change in the classroom (Kubota, 1997). Lack of comfort with content is frequently cited as a reason that teachers fail to teach science effectively and as a major inhibitor to the risk-taking required for innovation (Allen & Lederman, 1998). Engagement with content and demonstrated mastery of content both renews teachers' interest in the content and increases teachers' comfort level with the content, thereby increasing the likelihood that they will experiment with innovation. Dana (1997) noted that "teaching science so that students learn with understanding requires that teachers understand child development, pedagogical and assessment alternatives, and scientific conceptual and procedural knowledge." (p. 427)

Dana further observed that "effective preservice and inservice professional development programs must not operate as a deficit model, trying to remediate deficiencies in elementary teachers' knowledge and skills associated with science and science pedagogy. A more productive model is one in which teachers are viewed as learners of science and science-related pedagogy." (p. 428) Teachers tend to teach in much the same way as they were taught (Kubota, 1997). This emphasizes that professional development instructors should model the pedagogical practices identified as effective in elementary science instruction. Pedagogical ideas will enhance teachers' creativity in instruction through helping teachers identify age-appropriate avenues to help students engage the content objectives (National Science Foundation, 1998).

A Specific Implementation Goal

Professional development activities should be designed to result in a specific product or a commitment to create and implement a specific product by a certain time. Workshop and other experiences often present a large quantity of material in a short period of time. Teachers then return to their normal daily duties with more knowledge but without an identified way of increasing teaching effectiveness based on this new knowledge. Teachers committed to produce a specific product are more likely to implement at least one innovation as a result of a development activity (Whitworth, 2000).

Products may include a lesson plan, a classroom activity, or other items. A complete goal should include at least four components: a product, a target date for implementation and/or experimentation in the classroom, an assessment of effectiveness, and a means of reflecting on the product and receiving feedback from other teachers. An effective program on our campus involved the use of letters teachers wrote to themselves which included a self-selected goal for a project. The workshop instructors collected the letters and then mailed them to the teachers at a later time as a personal reminder.

Teachers are pressed for time, so they seek a real product that is developed in the professional development experience and then implemented immediately in the classroom. Teachers tend to view professional development activities that result in such products as worthwhile and relevant. Teachers should also leave the professional development experience with the materials necessary for implementation of the product. Other features of easily implemented innovations include classroom sets to allow active learning strategies, efficient storage to allow the activity to be used more than once, and limited cost due to expendable supplies.

School and district administrators will value and encourage participation in professional development activities that result in products with clear connections to state, district and school initiatives (Allen & Lederman, 1998). In Texas, curriculum content is defined by the Texas Essential Knowledge and Skills (TEKS) and school effectiveness is determined, in part, based on student pass rates for exams over the TEKS. Therefore, administrators are more likely to endorse professional development activities which equip teachers to be more effective at teaching specific TEKS-defined topics.

Strengthened Connections Between Teachers and a Broad Variety of Instructional and Community Resources

Resources might include the curriculum specialists at educational service centers, faculty at universities, local resources (stores, fire stations, zoos, etc.) that provide field trip opportunities, local museum agencies and others (Allen & Lederman, 1998; Kubota, 1997; Ramey-Gassert, 1997; Dana, 1997). A goal of a long-term professional development program should be to create a support community committed to enhancing the effectiveness of both teaching and learning (O'Brien, 1992). In view of the turnover rate among early career teachers found in many schools and school districts (Recruiting New Teachers, Inc., 1999; Wolff, Cook, Rodriguez, and Colbert, 1997), long-term commitments to meaningful involvement in professional development activities will be needed from schools, districts and communities.

Conclusion

As we enter a new millennium, the quality of life in the decades to come will depend to a great extent on the quality of our schools. A hallmark of that quality will be our ability to provide effective science instruction for all students. Our success in achieving that objective will depend on teachers at every level who are well-equipped and well-prepared to teach science. Staffing our classrooms with teachers who are able to provide quality science instruction, though, will not be easy. It will require commitment and collaboration on the part of teachers, administrators, teacher educators, and many others. Nor can we assume that, once in the classroom, teachers will remain well-qualified and well-prepared. A clear understanding of effective professional development, and continuous implementation based on that understanding, will insure that we have the teachers that we, and our students, will need in the coming century.

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THE NATURE AND HISTORY OF SCIENCE IN 9TH GRADE PHYSICAL SCIENCE

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Introduction

With the 1962 publication of Joseph Schwab's The Teaching of Science as Enquiry, the science education world received a loud call for the use of a novel type of science teaching. This type of teaching was to emphasize the processes that science undertakes in its search for understanding in, addition to the final form that it takes in the textbook. Schwab characterized the traditional form of science education as a "rhetoric of conclusions" which omitted the methodologies and pathways to discovery in science. Although the knowledge of science is subject to change, the way that scientific knowledge emerges is relatively stable. Thus, students of science should be cognizant of the "how?" of science instead of simply the "what?"

This idea was not entirely new to the world of educational thought, although it was a newcomer in the field of science. John Dewey (1933) is credited with popularizing the idea that the origin of thinking "is some perplexity, confusion or doubt" (p. 15). Something in his or her experience must provoke the student in this activity. With this basis, and the call for reform in science education, new curricula were developed in the 1960's, many of which emphasized this idea of inquiry espoused by Schwab and Dewey. Through the use of inquiry in various aspects of the science classroom, these curricula would theoretically produce students who would better understand what a scientist does in the process of problem solving. If students become aware of the tentative nature of knowledge in science, they should become more literate, science-trusting citizens.

The use of inquiry and its goals have eventually led to a widespread recognition of goals in science education beyond mere cognitive gains in subject matter. The last decade or so of research in the field of science education has emphasized one such goal, as evidenced by the amount of research in understanding the Nature of Science (NOS). Typically, NOS refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). The definitions of what constitutes specific aspects of NOS have remained more ambiguous as various fields such as philosophy, history, science, and education have disagreed through an assortment of arguments and interpretations (Akerson, Abd-El-Khalick, & Lederman, 2000).

Although the conceptional specifications for what actually composes the nature of science are not a subject of agreement, specific goals relating to understanding aspects of NOS have found their way into position statements. For example, a National Science Teachers' Association's publication in 1982 called specifically for students to understand how society influences science (and technology), to understand the dependency of science upon the process of inquiry, and to recognize that scientific knowledge is tentative and subject to change through time as new evidence is accumulated (p. 1).

This leads to the question as to why should science educators bother to worry about including the nature of science along with the science content in their classroom? The Benchmarks for Scientific Literacy (AAAS, 1993) answer this question by stating that:

> When people know how scientists go about their work and reach scientific conclusions and what the limitations of such conclusions are, they are more likely

> to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically. (p. 3)

Essentially, it is argued that the purpose of statements such as those issued by AAAS are to help produce individuals who have an adequate understanding of the nature of science in order to participate in important decision-making activities in the scope of society (Smith & Scharmann, 1999). Note the similarities with the objectives of the inquiry approach to education.

Research of the last two decades has focused on the various views that both students and teachers have on several areas that have been widely accepted as characteristics of understanding the nature of science. Among these aspects of NOS are the ideas that scientific knowledge is tentative, based on evidence, produced from human inference, imagination, and creativity, connected to society, and subjective (Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, et. al., 2000; Lederman, 1986; Solomon, Scot, & Duveen, 1996). The majority of this recent research tends to focus either on the conceptions that teachers (both practicing and pre-service) have, or on the relationship between a teacher's understanding with his or her students' understandings.

Although it was initially believed that the conceptions held by a teacher would be directly or indirectly conveyed to the student, research on this idea suggests that this is not the case (Lederman, 1992). As with many aspects of the educational process, there have been found to be a number of classroom factors involved with a student's understanding of NOS. Ziedler and Lederman (1989) have given evidence that the language a teacher uses during daily discourse has a strong bearing on the student's interpretation of NOS. In addition, Lederman and Druger (1985) showed 25 other classroom variables related to student's overall and tentative conceptions. Some of these factors included the degree of "warmth", the relationship to a student's personal life, the student's anxiety level, the amount of student-centered activity, and the amount of questions asked during the course of class. With such a great deal of ambiguity it has been somewhat unclear as to how learning should occur in the classroom in order for students to show desired outcomes in relation to the ideas of NOS.

More recent research has focused on whether an implicit or explicit approach to teaching the nature of science seems to be more productive. This line of study has provided evidence suggesting that explicit reference to areas concerning the nature of science brings about more substantial gains when compared to implicit instruction (Abd-El-Khalick, 2000; Akerson, et. al., 2000). In extending this line of thought to student-learning, Abd-El-Khalick and Khishfe (2000) found that supplementing inquiry activities with reflective, explicit references to the nature of science led to greater understanding of the tentative, empirical, inferential, imaginative, and creative areas of NOS. These studies refute that past ideas suggesting that students would implicitly learn NOS from indirect sources, such as inquiry activities or discussion. Directly addressing NOS may produce more positive gains in this area. This implies that mere inquiry activities may help students in their problem-solving skills, but they may not necessarily aid students in improving their specific conceptions of the nature of science.

One method of approach that has been taken in helping students achieve understanding of how science knowledge originates is through the direct use of historical vignettes. If the goals of inquiry and NOS are to produce students who have an understanding of how science works, then emphasizing historical cases of scientific inquiry should provide a concrete aid for students (Monk & Osborne, 1997). A reading of James Conant's (1966) case histories elegantly illustrate the myriad aspects of NOS by showing how scientists, such as Robert Boyle and John Dalton, were able to arrive at the conclusions that led them to their placement in modern science textbooks throughout the world.

With this goal in mind, The Project Physics Course (Rutherford, Holton, & Watson, 1970) has been perhaps the only large-scale curriculum developed with a thorough emphasis on integrating the history of science into the science class. A brief summary of research into this course (Russell, 1981) reported that students finishing this curriculum viewed physics as a course that was historically interesting, not dependent upon mathematics, and diverse. In addition, no significant differences were found in this course when compared to traditional physics courses when cognitive scores were examined (achievement test, course grade, score on the Test of Understanding Science, and the Science Process Inventory). By introducing the history of physics, the developers of this curriculum were able to generate the changes that were desired with this physics course.

Other than the Project Physics Course, there has been very little written about substantial use of science history in the standard science classroom. Various reasons for this, such as lack of curriculum materials, knowledge by science teachers, and time to introduce topics into the standard sequence of content have possibly contributed to this absence (Monk & Osborne, 1997). Occasional studies, such as Nott's (1994) description of using Brownian motion and Irwin's (2000) teaching of atomic theory, appear to illustrate the utility of using such aspects of history in the classroom. However, these studies are few and far between. Our knowledge of how using such topics in the science classroom broadly translate into change for both student and teacher is lacking.

This study attempts to determine how the use of historical cases in science, along with explicit inquiry-oriented activities, influence ninth grade physical science students at a small, rural high school. In particular, assessment was made to determine changes in student attitudes toward science, cognitive changes in course content, and specific changes in conceptions about the nature of science for students involved in this course. The study also seeks to report how the teacher-as-researcher experienced changes in pedagogical content knowledge and understanding of the nature of science during the process of researching, reading, and teaching the course in this manner.

Methods of Study

(Note: The study described here was conducted in the personal science classroom of the first author. Collaboration between authors occurred in the design of the study, in data collection, and in analysis. In describing the procedures used, the utilization of the first person in writing signifies the voice of the classroom teacher (Spellman).)

Population

Browne County, with a population of about 12,000, is a rural area in eastern Georgia located approximately 30 miles from the nearest medium-sized city. Like many rural counties in this area of the state, there are high levels of poverty and small percentages of citizens with education beyond high school. The high school that serves this county is the only one in the district, with about 700 students enrolled in grades 9-12. Ethnically, the school is about 88% African-American, and about 12% White. There are a handful of students from Mexico and the Philippines, but these combine for less that one percent of the school enrollment. A reflection of the larger community in terms of poverty, over 90% of students are eligible for federally subsidized free or reduced meals.

As measured by state standardized tests, the school and the school district are among the lowest scoring in the state. For example, students at Browne score poorly on the statewide science exam that students must pass as a part of a battery of tests for graduation. While the state pass rate for first-time test takers in the state is about 75%, juniors at Browne pass at about a 40% rate. Most students do not pursue education beyond high school.

The state graduation requirements in Georgia at the time of this study call for three courses in science, one of which must be a physical science and one which must be a biological science. The sequence of these courses may vary between high schools, but physical science is generally a 9th grade course in most schools, as it is in Browne. There is a high failure rate at the school of students in physical science, so these courses are usually a mixture of students from all grades, although 9th graders make up the largest percentage.

Because of the many social factors described above in this community, the school often looks for ways to assist students in being successful. One program with this in mind is Project Success. This program selects rising 9th graders who are considered to be "at-risk" for having academic problems in high school. The screening process involves 8th grade standardized test scores, teacher recommendations, and behavioral considerations. Most students invited into the program have struggled academically in school, but do not have a history of behavioral problems. None of these students receive special education services.

Students in Project Success attend the same classes with one another and have the same teacher for their areas of content. For example, all students in this program came to me for physical science. The benefits of this are to increase communication between content teachers of these students and to have these students work with one another in all of their classes. It is almost as if the middle school cluster concept is extended into high school. These students' parents are contacted more frequently than other students, and a paraprofessional works with the director of the program in the school to keep up with how the students are doing in their courses.

This study took place in the fall of 2000, using two sections of physical science in which Project Success students were enrolled. These classes were atypically small for public school, with ten students in one section and 20 in the other. This is a characteristic of the Project Success program that serves to give teachers more opportunity for individual attention. Males and females were almost equally represented, with 14 of the former and 16 of the latter. The racial composition in these two classes largely mirrored the school, with 26 African-Americans, three Whites, and one Latina.

Teacher

During this course, I was at the beginning of my fifth year teaching science at this school. Although my background is in biology, this was the fourth year in which I taught physical science. In addition, this was the third year of my involvement in the Project Success program. After becoming more interested and knowledgeable about the history and nature of science throughout my graduate programs, I wanted to find out whether or not it was feasible to incorporate these aspects into the traditional physical science content. Prior to these courses, my physical science teaching tended to mirror the content in the students' textbooks, although activities and lab experiences outside of the text were often incorporated into the class. As my knowledge of physical science content grew, so did my confidence and ability grow to branch out from what was presented in the text.

Teaching the Course

Because of increased "accountability" of teachers in Georgia and the importance of standardized testing, my ability to stray from the state curriculum was limited. During this 18-week semester (students attended 90 minute block classes), the course needed to cover science methods, mechanics, electricity, atoms, and all of the other topics traditionally taught in such an introductory course. Thus, there was very little time to spend on "extra" activities to help students to better understand the nature of science (NOS). Nevertheless, several activities were chosen that explicitly addressed key areas of NOS. These activities did not take significant chunks of instructional time and were appropriate to several of the state curriculum guidelines. Additionally, historical aspects of physical science were incorporated into the class to show examples of how science actually proceeds. It was hoped that these historical lessons would show a more personable side of science and reinforce aspects of NOS, such as creativity, tentativeness, and the role of evidence in making claims. Although discussion and lectures often pointed out aspects of NOS, the following activities were incorporated in the class to promote greater understanding of NOS:

(1) Inferential cubes: This activity was adapted from Lederman & Abd-El-Khalick (1998). Students were presented with cubes made of paper. Five sides were visible, but one was covered with a piece of paper. Students were challenged to make a claim about the covered side of the cube by using patterns found of the uncovered side. For example, one cube was designed to have opposite sides paired with a holiday and a month. Opposite sides were: October-Halloween; November-Thanksgiving, and December-Christmas. Students were to write about what they thought was on the covered side and provide reasons for their claim. Several different cubes were used, and some were more ambiguous than others, prompting different groups to arrive at different claims. Discussion followed about reasons students made the claims they chose and how aspects of science, such as theory development, often work the same way.

(2) Tricky Tracks: This activity was also adapted from Lederman & Abd-El-Khalick (1998). Student viewed a series of overhead transparencies showing animal tracks. The series shows two sets of different tracks intersecting concluding with only one set of tracks leaving. Students wrote their observations and were asked to make explanations of their observations. Discussion followed that highlighted the difference in observation and inference, and also emphasized how different observers may make different conclusions based on the same data.

(3) The Aging President: Also adapted from Lederman & Abd-El-Khalick (1998). Students viewed a series of drawings that appeared to be President Reagan. In the handful of drawings, the face of Reagan eventually becomes a drawing of a woman. I asked students to write their observations of President Reagan as he aged. By telling the students what they were looking at beforehand, the goal is to have students understand how looking at something from a particular point of view or belief system may cause them to miss out on seeing other things. Discussion followed in which the activity was related to science in areas like theory development where old ideas often dominate new ways of seeing things.

(4) Thermometers: Before discussing heat and energy, students heard a brief lecture about the development of the thermometer. The goals of this were to show students that our concept of temperature is a human-invented notion. They also were told of problems in developing accurate and practical thermometers throughout history, such as standardized glass blowing and suitable endpoints of measurement. I concluded this by demonstrating the principles that are at work in a thermometer by building a rudimentary thermometer using a glass jar, a pipette, and sealant.

(5) Joseph Black and the Concept of Heat: During the unit on heat and energy, students learned of how our current notions of heat and heat capacity developed. The inspiration for these lessons came from Conant's (1966) Harvard Case Histories. I created a one page reading for the students that introduced them to thinking at the time Black experimented. The reading consisted of Black's actual writings along with explanations that I provided for the students. These readings were followed by a laboratory activity that simulated Black's work (we used water and safe metals instead of mercury). Students experimented with adding the exact volume of water at different temperatures to find the resulting temperature. They also worked on adding different volumes at different temperatures to predict results. To introduce the concept of heat capacity, the same

volume of different materials were mixed together to arrive at final temperatures. For example, 100 ml of room temperature water was added to 100-degree, 100-ml (C) brass. Discussion occurred after activities to show how the results of Black's experiments resulted in different explanations from what others believed.

(6) Pneumatics and Boyle: When covering the unit on pressure, I showed students drawings of the apparatuses used by Toricelli and Boyle to arrive at our conceptions of air pressure. Boyle's Law was explained by showing how he developed it through experimentation.

(7) Mendeleev and the Periodic Table: Students used data from the elements known when Mendeleev developed the periodic table to predict characteristics about elements that would be discovered in the future. The goals of this activity were to show students how the periodic table was arranged and to help them understand how science proceeds. I explained how Mendeleev was largely ridiculed when he developed his original table, but was held in high regard when the elements he described to be found in the future agreed with what was later found. The role of inference and patterns, creativity, and theory development were all prevalent parts of this lesson.

Data Collection

Data were collected using several sources, although the realities of teaching and attempting to conduct research in a public high school constrained us from exhaustive collection. The original plan was to compare these students with other classes of physical science students in the same high school. As the semester began, however, it was not feasible to collect data from all of my students and from the students in other classrooms. In addition, because of the different characteristics of students in those other classes and the differences in the teachers, it would be difficult to make meaningful comparisons at the end of the course. When possible, data were collected from other physical science classes. Although the purpose of the study is primarily descriptive, some comparisons were made between groups.

Pre-Post Test

By mandate of school administration, all teachers must develop a test for their classes to give at the beginning and end of the course. For my physical science classes, 50 multiple-choice questions representing content from throughout the course were selected for the test. The questions chosen came from the bank of questions provided by the publishers of the textbook for the class.

Likert Questionnaire

A 36-item, five response Likert questionnaire (Appendix A) was administered to my two classes at the beginning and end of the semester. Students from another physical science class completed the same questionnaire at the beginning of the course. Six subscales composed the 36 items. The first subscale (ATT) had six items attempting to profile attitude toward science (Simpson & Troost, 1982). Items from two subscales of the Scientific Attitude Inventory Revision (SAI2) (Moore & Foy, 1997) made up two additional subscales on the student questionnaire. The first subscale (5A-B in SAI2) profiles responses to the need for the public to be made aware of the nature of science (AWARE). The second (6A-B in SAI2) profile attitudes about being a scientist or working a job requiring scientific knowledge (WORK). The final three subscales were taken from the Nature of Scientific Knowledge Scale (Rubba & Andersen,1978). These three scales profiled responses to the creative (CREAT), developmental (DEV), and testable (TEST) aspects of NOS. Individual items from the original instruments were omitted in the administration of the questionnaire in this study. The reason for doing so was to arrive at an instrument that was not too long for students to complete. In working with past students, it was my experience that students hastily complete longer questionnaires. Most items omitted from this questionnaire were the negative form of questions that were included in the instrument. For example, the item "Scientific laws, theories, and concepts express creativity" was included from the NSKS, but "Scientific laws, theories, and concepts do not express creativity" was omitted. Although the value of negatively worded items is appreciated, including all items on each subscale would have added thirteen more items to the instrument.

Views on the Nature of Science (VNOS) Questionnaire

Students in my physical science course completed a seven-item, open-ended questionnaire (Abd-El-Khalick, 2000) aimed at getting responses about target areas of NOS (Appendix B). Students from one other physical science class also competed the questionnaire.

Interviews

The second author conducted 24 interviews on two separate occasions at the school where the study was conducted. These interviews were brief (10-15) minutes and attempted to determine students' understandings of science concepts and particular aspects of NOS. The first day of interviews was less structured and asked students about examples of science when they leave school, the role of evidence in coming to understand something, and understandings of the terms "hypothesis" and "inference". The second set of interviews were slightly more structured, somewhat is response to the first interviews, and asked students about scientific concepts related to the burning of a candle. Using this specific event, students were asked what science concepts were involved in the burning of a candle. They also were asked to speak of scientific laws and theories related to the candle burning. Students were also asked about creativity in science and whether or not scientists are able to be creative or whether they just "follow the rules" of science.

Journal

I also kept a journal of activities and reactions that surfaced throughout the course. The entries were used to reflect upon the effectiveness of the approach used in the course.

Data Analysis

Descriptive statistics were calculated for quantitative data. Mean scores for the pre- and posttests were calculated. Data gathered from the Likert questionnaire were entered into SPSS version 10.0 (1999). Values for negatively worded items were inverted on the scale when entered into analysis (a value of five became a value of one). Descriptive statistics were generated from data provided by the students in my class at the beginning and end of the semester, and from a comparison class at the beginning of the semester. Since data were collected anonymously, means were compared using independent samples methods. Means were compared in my class at the beginning and end of the semester, and between the two different groups at the beginning of the semester. Alpha reliability for each of the six subscales was also calculated using SPSS.

The VNOS was analyzed in ways comparable with previous authors. Previous papers (Abd-El-Khalick & BouJaoude,) have coded student responses into categories of "naïve" or "informed". We coded their responses similarly, but added one more category. Thus, items were coded into three categories: (1) blank, or naïve response, (2) informed, and (3) intermediate. We felt the addition of a category in between naïve and informed was warranted based on the responses given by many of the students. Each researcher independently coded the data using this method. The agreement between the two sets of codes was unacceptably low (47%). Of 133 responses by students participating in the study, there were 70 disagreements between the researchers as to the level of categorization. Further examination of these differences, however, revealed a consistent pattern in these discrepancies. In all but five of the disagreements, I scored the student lower than the co-author. It became evident that my level of acceptance to responses was more stringent than the co-author. Perhaps because I knew the students much better, or my biases about desiring model responses could have contributed to this. With this in mind, I reviewed the student responses where differences existed and became more open to the possibility that students were more informed than I gave them credit for. After proceeding through these 70 disagreements, the number was reduced to twelve (less than 10%). Naïve responses were assigned a value of "1", intermediate a value of "3", and informed a value of "5". Responses that showed disagreement received a value that was the average of scores given by each researcher.

Because of time constraints, the responses given to the VNOS by a comparison class were only coded by one of the researchers. These were coded after the first set of VNOS responses was re-coded. Thus, even though the second researcher did not check these, the values assigned should be fairly consistent with those of the first group. Conclusions drawn from a comparison of these results should keep this limitation in mind.

Student interviews were audio taped and loosely transcribed, by making notes of the conversation. Many of the students did not have very much to say during the interview, and it was decided that time would be better spent simply listening to the tapes and taking notes of the conversation. Some sections, in which students spoke freely, were transcribed verbatim. The two researchers spent time discussing the results of the interviews and the troubles of drawing conclusions about their understandings of NOS from those interviews. These interviews were ultimately used to provide additional insight into some problems of assessing student NOS understanding.

Results

Pre/Post Tests

Scores on the standardized test given at the beginning and end of the semester increased significantly, t(54) = 6.852, p<.01. The number of students taking the exam at the end of the semester dropped from 30 to 26 due to reasons such as transfers and drop out. Although scores rose significantly at the end of semester administration, the mean score was only 50.8%. Only one of the 26 students scored above 70%.

Likert Questionnaire

Alpha reliability for the six subscales is shown below.

Table 1

Alpha Reliability of Likert-Item Subscales

Attitude Toward Science	.8799
SAI 5 (Awareness)	.3122
SAI 6 (Work)	.6820
NSKS Testability	.3552
NSKS Developmental	.0945
NSKS Creativity	.2732

Most of these subscales show lower reliabilities than have been reported previously in studies using the questionnaires from which these came. The ATT subscale's reliability, however, is similar to previous studies (Simpson & Oliver, 1985).

Of the 30 students enrolled in the classes under investigation, 23 completed the questionnaire. When compared to a sample of 15 students from a college preparatory physical science class, no significant differences were found between the groups in any of the subscales. In fact, only one difference in the 36 items was found. This item was "Scientific theories are discovered, not created by humans."

When examining the beginning-end questionnaires completed by students in our classes of study, no significant changes were found in any of the subscales. The number of students completing the questionnaire dropped to 19 in the second administration. Five individual items (2, 4, 7, 16, 20) showed significant change, with four responses decreasing (all but item 2). The ATT scale was the only one that had more than one item significantly decrease.

VNOS Questionnaire

The VNOS questionnaires were completed at the end of the semester by 19 students in the investigated class and by 16 students in another physical science class. Results of the coding are shown in Table 2.

Table 2

Coding of Responses to VNOS

Code Value	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7
1	2 (3)		4	3 (1)	5 (3)	(2)	7 (4)
2			1	2	1		2
3	13 (11)	11 (4)	6 (4)	7 (2)	12 (10)	10 (4)	5 (7)
4				1		3	2
5	4 (2)	8 (12)	8 (12)	6 (14)	1 (3)	6 (10)	3 (5)
Mean	3.21 (2.88)	3.84* (4.50)	3.37* (4.50)	3.26* (4.50)	2.53 (3.00)	3.79 (4.00)	2.58 (3.13)

Note - Values outside of parentheses indicate number of students in the study class who received that rating. Values within parentheses indicate number of students in another physical science class who received that rating.

Although these differences should be tempered by the fact that the scores of the comparison group were not checked by one of the researchers, the responses given by students in the classes exposed explicitly to NOS instruction provided less informed views than those in regular physical science classes.

In examining the responses provided by the students in the NOS-emphasized class, it is evident that most of the responses received a value of three. Responses with this rating provided some evidence of an informed view, but did not reply with enough information to warrant a rating of "informed". To give an idea of the variety of responses given and how they were rated, two responses for each item are provided below. These responses show the extremes of informed and naïve replies from our participants.

Item 1. "Science looks for evidence. Then it reasons and gives an educated guess (5)." "In my view science is the study of things around us. I don't think science is different from religion (1)."

Item 2. No students received a rating of "naïve" for this item. Almost all responded with some variant of "testing a hypothesis", although some students provided more thorough responses than others.

Item 3. "It can change, but as far as you just saying it's changing, that's not possible. You have to detect changes. You have to know when and something happens and have proof to change things like this (5)." "I think theories do change because over time it may get bigger or smaller. So it may move in another place. For example, the earth moves so that's why the seasons change (1)."

Item 4. "Yes, a theory is a guess brought on by evidence. A law is a fact and has been seen or done (5)." "Scientific theory is different because you can't explain a theory but you can explain a law (1)."

Item 5. "…They probably were just using data, information or drawing things and came up with the design of the atom (5)." "I myself think that this structure or form of atom isn't true because an atom is so small until you just can't see them if they can't be seen how do they know what they look like (1)?"

Item 6. "Yes, because that's what most scientists do. They use their minds to think and see what way they can find out how to do certain things. They are people known for making up things out of their head (5)." "No, because they use data and information that will help them find answers to their problems (1)."

Item 7. "Because if they read the same data the two groups probably read the data in two different ways (5)." "They might have come up with an idea on why the dinosaurs went extinct (1)."

Interviews.

The design of the interviews was planned to follow up on items given in the previous questionnaires, assess understandings of science content, and seek to investigate how students relate evidence to science. Because of the lack and brevity of responses by students during these interviews, it was difficult to follow the original protocol, especially in following up responses to the VNOS questionnaire. Thus, most of the time spent in these first interviews ended up with a focus on students' ideas of science in their life and the role of evidence in coming to know things about nature.

In asking about science in their lives beyond school, students tended to identify objects or processes that were a part of school science. The following is a partial list of student responses: light; insulin shots; plants; chemicals; pollution; condensation; and technology. None of the students gave answers that dealt with scientific processes, such as experimentation. In some cases, students could not explain the reason why they provided a specific concept as "scientific". One girl explained that pollution was science, spoke of CFC's, knew what CFC meant, and spoke of how CFCs damaged ozone. But when asked why CFCs were part of science, she did not (or could not) provide a response.

Further probing of students revealed that they had a good grasp of what evidence is and how it is used to make claims. One student, when asked how he knew what type of bait to use when fishing explained his choice through looking at the water. He responded that muddy water was good for catfish, while clear water was good for bass and crappie. The basis for his claims was experience and observation of water habitats during various conditions. Adding to this, he also noted that water temperature is important in making fishing decisions. When asked if this was an example of science, he responded that it was because someone could prove that the temperature of the water was related to the amount of "action" when fishing.

This conversation with one student was typical of many of the interviews. Students failed to relate evidence as a part of what they considered science, but had little problem of giving examples of evidence and how it is used in making decisions. When prompted, most could explain how evidence might be able to be used in science. Thus, it is difficult to assess the understanding that students have about the role of evidence and testability in science.

Most of the students participating in this interview were asked about the term "hypothesis". Almost all students responded to this in one of two ways: "testable prediction" or "educated guess". When asked to go into more detail, some students struggled beyond this basic definition and could not apply the term in any context. Two students provided examples of a hypothesis from laboratory activities they had completed during the physical science course. One student went so far as to apply it to his everyday life in stating that one could hypothesize about who would win a football or basketball game. When asked about the factors that went into the hypothesis, he noted that previous performance and the talent of the players would play a part in making such a prediction.

The last topic of these first interviews, although not all students had time to get to this point, was about the role of inference in science. Most students could not define what an inference was, although many said that they had heard the term before. Like their discussion of evidence, many provided examples of inference after a brief discussion with the interviewer. Many students were asked about streams near their house and their conditions, many of which had no fish. When asked why there were no fish, some responded about pollution or lack of water. Another student said that it would be an inference by thinking that the neighborhood dog was responsible if he came home and found trash in the yard. Students seemed to have difficulty in showing their understanding of inference as a critical part of the scientific process, however.

After the initial interviews, a second round was planned. Because of the problems students had in speaking of science, the second interview focused on a specific event that could be considered scientific: the burning of a candle. This was also related to many topics that students had studied during the semester in the science class. It was hoped that this situation would allow more meaningful discussion and insight about their understandings of NOS. The interviews surrounding the phenomenon of the candle were fairly consistent in the responses given by the students. A typical session is provided below:

Interviewer (I): What science concepts are related to the burning flame of a candle?
Participant (P): Chemical change.
I: How is it a chemical change?
P: Burns and turns to steam.
I: Others?
P: Energy. Heat.
I: How are we making heat?
P: Burning.
I: How much heat?
P: (No response)
I: How could we figure out how much heat is being made?
P: (No response)
I: What if we put a test tube of water over the flame? What would happen?
P: It would boil.
I: Could we measure how quickly…how could we do that?
P: Use a thermometer…time the boiling.
I: How else?
P: Measure the steam.
I: How could we make a hypothesis about the heat given off?
P: (No response)
I: What is a hypothesis?
P: A guess…estimate.
I: How can we test the hypothesis?
P: Experiment. Time it.

Another common theme in the interviews involved students' naïve conceptions about what happens to the mass of a candle as it burns. Almost all thought that it would remain the same. The interviewer used this opportunity to express that he disagreed and thought that it would decrease. At this point, the student was asked how they could determine who was correct without going to ask someone else. Almost all students pointed out that they could do an experiment and look at the data/weight after it burned.

Students were also questioned as to whether or not they knew of any theories or laws that related to the burning of a candle. Some named concepts such as "melting", but several spoke of the law of conservation of mass/matter as being related, although not all of these students exactly named this law. A couple of students spoke of "something about what you start with is what you end with." Students who spoke of this law could accurately define it, but struggled with applying it to the candle burning. Some interpretations were "that how ever much candle you started with, that's how much you would have in the end." The invisibility of products in the burning of the candle posed a problem. Students spoke with more informed interpretations relating the law of conservation of matter with the burning of wood because they could see the smoke going into the air. Nevertheless, their conviction that scientific laws are "proven" eventually led many to realize that the same processes that occurred in the burning of wood were the ones that occurred in the candle. Thus, like the mass of the wood after burning, the mass of the candle also decreases. Even though many voiced correct scientific conceptions of the law of conservation of mass, their application of it to the burning of the candle was much less appropriate.

Lastly, several of the students had time in their interview to be asked a question about the creativity of scientists, similar to the item on VNOS. Most of the students responded that scientists are creative or use their imagination. But when asked how they use their imagination, no response was often the case. In cases where a response was provided, it was often not helpful in understanding what the student thought. One student responded to the question of "How?" with, "They think they know something but they don't." One student, when asked whether scientists use their imagination or follow the rules chose the latter. It was refreshing, however, that one girl cited Mendeleev as an example of a scientist who used his imagination and creativity in designing the periodic table.

Discussion

Like other studies in a similar vein, it was hoped that students exposed to explicit instruction to NOS through both NOS-specific activities and the history of science would show informed views about various aspects of NOS. Also like those studies, our results showed that the outcome was less than desired. Although it is not our belief that the use of these strategies in the classroom was detrimental in any way, there are several considerations to take into account as to the lack of benefit.

The use of instruments for data collection and the design of the study imposed limitations. Attempting research in a typical classroom setting without outside researchers or assistants has benefits and drawbacks. Resembling other classes that students attend, there is little chance of a Hawthorne effect caused by students realizing that they are a part of something special. However, the lack of time on the part of the teacher to collect loads of data, especially through interviews and videotapes, poses limitations on data collection and analysis. The choice of having the researcher from outside of the school conduct interviews may have contributed to the lack of dialogue elicited from the student participants. However, biases about students after 18 weeks of class time may have caused other problems with the interviews had they been conducted by the classroom teacher.

The small sample size was problematic for the Likert questionnaires. Ideally, the classes would have been slightly larger and provided more meaningful results. The alpha reliability was low on many of the subscales. It was possible that many students did not take the time to thoroughly read and think about the items. Although the pooled items of the subscale did not change from the beginning of the course to the end, the scale that had the highest reliability (ATT) did have two items that dropped significantly. These attitude items related to how "fun" the students viewed the science class and their attitude about being a scientist. It was hoped that exposure to how real science and scientists work would lead to more positive attitudes, but that was not the case. Another aspect, student grades, may have played a factor here. Unfortunately, the students in these two classes were very low achieving in terms of scores on test/quizzes and completion of other assignments. A greater number of these students failed to pass the course than would have been expected. At the time of the second administration of the Likert questionnaire, many students knew they were not going to pass, which has been shown to relate negatively to student attitude toward science (Rennie & Punch, 1991).

The use of the VNOS and interviews were intended to get around the inherent drawbacks of closed choice instruments. However, these were less useful for data analysis than was hoped, due mostly to the brevity of responses and lack of communication in the interviews. Elby and Hammer (2001) address the difficult issue of assigning students to categories of epistemological sophistication or naivety based on questionnaires and interviews. Most student responses to the VNOS were one sentence in length, making it very difficult to interpret whether or not they had an "informed" view of the item's topic. In addition, the interviews were often unable to clarify positions because of both the students' weak conceptual knowledge in science and their inability to see science outside of school science. Although students may have described science as "looking for evidence" on the VNOS, their words in the interview voiced the idea that certain topics, not a way of thinking, exemplified science.

Because of our belief that the concepts of evidence and testability are of the highest importance in understanding NOS, the interviews often covered student conceptions in these areas. Many students exhibited scientific ways of thinking about things in their everyday lives. Others showed the ability to speak of testing a claim to find out if one person or another's assertion was correct. However, they largely did not demonstrate this unless engaged in a conversation specifically addressing some specific context, such as catching fish or the melting of a candle. Other methods of data collection or interview designs may have been more effective at determining whether or not students truly understand the nature of science as relying upon evidence for making claims.

Another consideration about the apparent lack of informed positions demonstrated by students is in how the class was taught. Although conscious inclusion of NOS aspects was in the course throughout the year, it only constituted a fragment of instruction when compared to other content. Russell (1981) asked the question as to how much history of science should be included in a science course. His response was that significant content should be included if we wish for changes to occur in students. Although several days were spent in historical discussion or activities, it was unlikely considered to be significant. More significant in the class was a weekly vocabulary quiz that students had on each Friday to review science concepts previously covered. This stemmed from the low pass rate on the state science graduation rate for the students at Browne. Administration encouraged teachers to continually review students in content. Additionally, the largest portion of a student's final grade came from chapter tests and the vocabulary quizzes. The rationale (adopted by most of the science faculty) was that if students could not pass multiple choice-type tests about physical science as 9th graders, then they likely would not answer them on the state test two years later (the testing process is being revised in Georgia to year-end content tests). Thus, throughout the school there was much emphasis on testing, which inevitably leads to a focus on content and vocabulary. Student views of science were possibly influenced more by this than on the instruction about NOS.

This study adds to the body of research that largely has documented the difficulty in bringing about large-scale changes in students understandings of NOS through activities or emphasis in the history of science. Other studies showing moderate success with students of this age and younger seem to indicate the possibility that well-planned classrooms can have positive effects (Abd-El-Khalick & Khishfe, 2000; Solomon, Duveen, & Scot, 1992). Our research points to the numerous constraints in implementing significant history and nature of science instruction in the mainstream public secondary science classroom. Emphasis on standardized testing, lack of curricular materials, and lack of university preparation are strong barriers that must be considered when attempting to bring this focus on the history and nature of science to students.

Perhaps the primary and foundational goal of instruction in the history and nature of science should be in promoting scientific intellectual independence for students. Intellectual independence has been characterized by the following two features: (1) Evidence is provided in support of claims, and (2) the argument in support of a claim is present (Munby & Roberts, 1998). Additional features are also given, but these two form the basis for the others. Instruction in the history and the nature of science should provide ways for students to understand how people in the past have demonstrated intellectual independence in coming to know of the topics we teach in class. Students in this study exhibited signs of intellectual independence in activities outside of science, but struggled with relating the same ways of knowing relative to science. NOS activities should emphasize the concept of scientific intellectual independence. This type of instruction should serve as a foundation for later instruction in NOS, if appropriate. For the population of this study, of whom most will not further their education beyond the secondary school, teaching for intellectual independence may be in the best interest of both the student and the democratic society.

Our own study suffered from trying to accomplish too many things with too little time spent engaging students in H/NOS. Since it is unlikely that the amount of time available to a teacher in U.S. public secondary science classrooms is to increase anytime soon, the alternative to doing more H/NOS activities is to focus on fewer concepts. Perhaps activities more strongly focused on how science claims are based on evidence, and less focused on terms such as "inference" or "observation", more progress would have occurred in those areas. In addition, assessment tools specific to those activities might prove more beneficial than the ones used in this study. Lastly, data that attends closely to context and draws on both "naturalistic" and school settings may provide greater insight into what students actually believe (Elby & Hammer, 2001). Interviewing and recording students throughout the term, especially about specific science concepts that are covered in class, would exemplify these types of data.

The role of designing, conducting, and analyzing this type of research proved to be extremely challenging. Our experiences suggest that the "based on evidence" part of common NOS definitions would serve as an appropriate starting place in classrooms looking to engage students in understanding NOS. This may be even more appropriate in classrooms composed of younger students or with those who have weak conceptual knowledge of science. Frequent lessons about how we (science) know (or have come to know) the content covered in the classroom should begin to provide students a basis in NOS understanding. Additionally, classroom interaction that promotes the examination of characteristics that makes a field more or less scientific (Smith & Scharmann, 1999) would support NOS instruction. Providing such a foundation about claims made by science may lead to greater support of the peripheral aspects of NOS, such as the roles of imagination, society, and inference.

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PREPARING SCIENCE SPECIFIC MENTORS: A LOOK AT ONE SUCCESSFUL GEORGIA PROGRAM

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The transition from pre-service college intern to practicing classroom teacher is challenging. Studies show that as many as forty to fifty percent of new teachers will leave the profession within the first seven years (Gordon & Maxey, 2000). While there are a myriad of reasons that beginning teachers leave the profession, reasons often cited include the isolation and lack of support they receive in the school setting (Boreen, Johnson, Niday, & Potts, 2000). New teachers may need information about the school and school system, about the instructional and resource materials available and how to obtain them, as well as advice on organizing, planning, and managing the classroom environment. However, novice teachers may be unwilling to ask for help because they see the need for assistance as an admission of failure or an indication of their incompetence (Gordon & Maxey, 2000). These new teachers need support and guidance as they become acculturated into their new profession.

The projected shortage of teachers has prompted many school districts to enact programs to reduce the number of beginning teachers leaving the profession and to strengthen their competence in the classroom. One of the strategies being implemented is the development of mentoring programs, which can reduce attrition rate by one half or more (Odell, 1992). These programs can be win-win situations as the new teachers receive the support they need to feel confident in their development as professionals and mentor teachers experience rejuvenation as they reexamine their practices and beliefs and refine their own teaching strategies (Brooks, 1999).

Mentors need guidance and training as they develop the skills necessary to become effective mentors. For mentor training programs to be successful, several elements are necessary. Mentors need knowledge about teacher induction and the problems that new teachers face; training in observational skills, strategies for classroom management, and effective teaching; and knowledge of adult learners and the stages of teacher professional development (Gordon & Maxey, 2000). In addition to these areas, mentors may need information about strategies for helping new teachers develop pedagogical skills that are unique to the discipline of science teaching. With knowledge of these topics along with effective interpersonal skills, mentors are equipped with tools to help ease the transition for new teachers from student to practicing professional.

The state of Georgia has developed the Teacher Support Specialist Program to assist prospective mentors as they begin the process of preparing to provide support and guidance to those new to the profession. Successful completion of this program for either staff development units (SDU) or college credit enables Georgia teachers to add the teacher support specialist endorsement to their teaching license. Professors from three Georgia universities along with practicing classroom teachers worked together to create a program, Teacher Support Specialist in Science (TS^3), that would address the unique needs of science teacher mentors. Participants from the Valdosta area in the southern region of Georgia, the Athens area in the northeastern region of Georgia, and the Dahlonega area in the far northern part of the state collaborated in the 2000 session of the TS^3 program. The program is unique in that through the use of technology, teachers from three geographically separate areas of the state were able to work as a cohort to earn their teacher support specialist endorsement. In this TS^3 cohort, there were six participants from the Athens area, three participants from the North Georgia Area, and four participants from the Valdosta area. Of the thirteen participants, six were middle school teachers and seven were high school teachers.

The stated objectives of the TS^3 program based on the requirements of the state are to develop mentors who are able: (1) to demonstrate and discuss the critical attributes of effective science teaching practice, (2) to demonstrate skills in collecting and analyzing classroom observational data and in providing feedback, (3) to develop effective interpersonal skills in conferencing situations, (4) to discuss and demonstrate principles of adult learning and reflective teaching, and (5) to develop a calendar of activities to facilitate the professional development of a protégé (Northeast Georgia RESA, undated). To facilitate attainment of these competencies, mentors complete a 50 hour program of course work, followed by a 50 hour internship during which time they work with a protégé in a teaching situation.

To complete the 50 hours of required course work, participants engaged in various activities over the course of a summer. Using interactive television technology, the participants met in the early part of the summer to discuss the course syllabus and expectations, and to learn to use electronic bulletin board technology. After this initial meeting, participants were expected to read the textbook for the course and post reflective responses to the class bulletin board based on their readings. Later in the summer, the participants from all three parts of the state came together for a week of intense work on the University of Georgia campus. Following the week-long session, participants continued to submit reflective journals and postings to the class bulletin board.

When school resumed in the fall, each participant worked closely with a protégé who was either a student teacher, a new teacher, or an experienced teacher who was new to the school. Completion of the second portion of the course required that the mentors document 50 contact hours of interaction with their protégés. In addition, the participants met via interactive television four times during the course of the semester and continued posting to the class bulletin board.

Summer Course

Because the TS^3 program was designed specifically to prepare science teacher mentors, activities during the week-long course addressed both general skills needed by a mentor and skills unique to the science classroom. To promote development of these attributes, each day of the week-long session was divided into different activities facilitated by the instructors of the course. The sessions were designed specifically to meet the five stated objectives of the TS^3 program.

To demonstrate and discuss the critical attributes of effective science teaching practice was the first objective of the program. To meet this goal, instructors conducted sessions on science curriculum issues, classroom climate and managing the science learning environment, and effective science teaching using conceptual change and inquiry. Participants were given hands-on experience with an effective inquiry-based lab, followed by a discussion of traditional versus inquiry labs and how inquiry labs could be used effectively in the science classroom. Other discussions centered around aspects of the science learning environment and how to effectively manage them (Chiapetta, Koballa, & Collete, 1998).

Further objectives for the program included developing the skills needed to collect and analyze classroom observational data, as well as developing the interpersonal skills needed to foster effective interpersonal communication. To meet these goals, one session focused on mentoring skills and the clinical supervision cycle. Each supervision cycle consists of a pre-conference, observation, analysis and interpretation, post-conference, and critique of the previous four steps (Glickman, Gordon, & Ross-Gordon, 1995). Participants learned what should occur in these steps and why each is crucial to the process. Directive, collaborative, and non-directive approaches to working with protégés were addressed (Glickman, Gordon, & Ross-Gordon, 1995). Class discussions focused on effective approaches that could be used during conferences with protégés (Koballa, et al., 1992). Another session was devoted to different techniques that could be used to collect data in a science classroom. Participants learned strategies to collect data that focused on teacher questioning, teacher movement, student movement, and student behavior among others (Acheson & Gall, 1987; Glickman, Gordon, & Ross-Gordon, 1995). Tapes of student teachers were shown to allow participants to practice the strategies they had learned. Ways to analyze these data and share the information with protégés were discussed.

The fourth objective was to discuss and demonstrate principles of adult learning and reflective teaching. To address these needs there were two sessions, one focusing on the characteristics of adult learners and the needs of new teachers, and a second session devoted to promoting professional growth by reflective practice. In order to assist protégés, mentors need a clear understanding of the concerns of new teachers. To attain this goal, there was class discussion regarding the needs of new teachers and how to address them (Adams & Krockover, 1997). Participants learned about the phases of new teacher growth and how those phases corresponded with the school calendar (Moir, 1992). Participants worked to define reflective teaching and to develop strategies to help their protégés develop the skills and attitudes needed to be reflective practitioners (Sparks-Langer & Colton, 1991).

The final objective was the development of a calendar of activities to facilitate the professional growth of a protégé (see Table 1). To accomplish this objective, participants worked throughout the week to develop their own action plans to guide their work with their protégés. These action plans are unique to each school and situation but have some common attributes. Action plans are outlines that guide what the mentor and protégé need to accomplish during each month of the school year. They provide a framework to guide the work of the mentor and protégé and to ensure that all needs are covered. The action plans usually prescribe more intense amounts of interaction during the beginning of the school year that gradually diminishes as the year progresses. They are useful because there is a specific plan in place; coverage of topics is not left to chance. Mentors developed action plans to guide their work that were different depending on whether they would be working with a student teacher, a new teacher, or a teacher new to the school.

During the course of this week long session, activities included speakers, class discussions, and hands-on activities that helped the prospective mentors prepare for their roles of helping new teachers as they begin the first phase of their development as professional educators. Along with the acquisition of new knowledge, during the course of this time together, the bonds were formed that would allow these new mentors to mentor one another.

Fall Internship

During the fall semester following the summer course, the responsibilities of the mentors continued through a second 50 hour internship course. Participants worked in their own school settings with a protégé. They were required to log 50 hours of contact with their protégés. These hours could be comprised of both formal observations and informal interactions. A portion of the time requirement was met through the three required observation cycles that the

mentors

Late July Obtain TS^3 Assignment Info Prepare General Info packet Get BT's floating assignment/keys Get small gift for BT's cart Set up own room to free up time Find a desk/headquarters for BT Meet BT at new teacher's session Tour the school and provide map	**Fifth Month (December)** Discuss holiday traditions Invite BT to faculty party Discuss leave time/pay Discuss "holiday fever" Do something special for BT Discuss semester grading/scan tron machine/exporting grades
Preplanning Introduce BT to others in school Introduce BT to subject area teachers Get BT's gradebook/teaching books/supplies Help with desk and cart (if wanted) Discuss handbook after advisory groups Discuss general info folder Go over school schedule/discipline procedures Go over equipment/supplies/book assignments Organize a departmental luncheon Discuss Open House preparation Discuss 1st day activities/ rules/class procedures Discuss lesson plan/copy room procedures Help develop seating charts for rooms Discuss role as advisor Discuss PAGE and NSTA dues Train BT on Osiris and Integrade Provide BT with sample syllabus Give pep talk on last day	**Sixth Month (January)** Discuss schedule changes Write a welcome-back note Discuss BT's concerns Invite BT to GSTA conference Offer to observe again, if needed
First Week of School Celebrate getting through the 1st day! Review attendance policies Go over discipline issues and techniques Check each day to see if BT needs help Remind BT to prepare next week's lesson and papers Discuss special education modifications (if needed) Model reflection of the week's success/failures Show BT permanent record files	**Seventh Month (February)** Discuss GHSGT reviewing Discuss BT's concerns Encourage BT to reflect on year Discuss pacing of curriculum
First Month (August) Invite BT to observe class and conference Sit with BT at pep rally Invite BT to a home game Discuss any concerns of BT's Discuss club dates and rosters Discuss pep rally rotation Discuss picture day/get BT's Review GTEP process Discuss progress reports Discuss time management	**Eighth Month (March)** Discuss budget request/needs Discuss GHSGT testing weeks Offer to observe class if needed Discuss BT's concerns

Discuss pacing of curriculum **Pre-observation 1** **BT observation 1** **Post-observation conference 1**	
Second Month (September) Discuss parent conferences Discuss concerns of BT's Encourage BT to observe others Discuss 9-wk failure meetings **Pre-observation 2** **BT observation 2** **Post-observation conference 2**	**Ninth Month (April)** Discuss advisory registration Discuss prom and holidays Discuss BT's concerns Send an "almost there" note Discuss curriculum wind-up Encourage BT to check books Discuss Honor's Night and voting
Third Month (October) Give encouraging note to BT Check with BT about concerns Discuss 1st GTEP evaluation Suggest motivation techniques Discuss EXPO chaos and holiday Discuss homecoming activities **Pre-observation 3** **BT observation 3** **Post-observation conference 3**	**EOY/Post-planning (MAY)** Discuss end of year tasks Discuss finals/exemptions Discuss yearbook signing Invite BT to graduation Assist BT with purchase orders Help return books/media/keys Double-check EOY lists together Celebrate!
Fourth Month (November) Discuss holidays/lesson planning Plan a lesson with BT if possible Discuss BT's concerns Remind BT to prepare after-holiday lessons early	

Table 1: Sample Action Plan By Michelle Smith

completed with the protégés. The remaining hours were fulfilled by informal discussions that occurred between the mentor and protégé. These interactions depended on the nature of the relationship between the mentor and protégé and the concerns that the protégé had about his/her own teaching.

In addition to the work with the protégés, participants were required to make weekly entries in a reflective journal that was read by the course instructors. Postings to the class bulletin board were required at least twice monthly, however, many participants posted more frequently. Participants used the bulletin board to solicit advice and offer support. When participants struggled with a particular dilemma with their protégé, they posted their concerns to the bulletin board and other class members or instructors provided feedback and ideas for ways to solve the problem. Class members also posted words of support and encouragement as other participants shared their struggles.

Four times over the course of the fall semester, participants met via interactive television. During these sessions members of the group discussed successes and concerns in their experiences with their protégés. They often elaborated on ideas that they had previously posted to the bulletin board. Discussion between group members and instructors provided the opportunity to generate ideas for dealing with individual situations. Participants also shared positive experiences and strategies that had proved productive with their protégés. In addition, this time was used to provide clarification on course assignments and completion of required paperwork.

The final required assignment for the participants was the development of a case that chronicled some dilemma in their work with their protégés (see Figure 1). In this context, a case is "a description of a real or realistic classroom situation that incorporates all the facts needed to clarify and solve target problems" (Kagan, 1993, p. 705). The participants then presented these cases to other teachers from around the state at the Georgia Science Teacher's Association conference in the spring. In this way, participants shared their experiences with other educators across the state.

During the fall, the mentors were intensely involved in their work with their own protégés. Each of these partnerships was unique. Because of individual differences, some partnerships proved more successful than others. Program participants used their fellow class members and instructors as resources and sources of encouragement as they worked to help their protégés.

New Teacher in Town: Lisa A. Anderson

This is an open case where I as a mentor am struggling to find ways to help my protégé. My protégé Susan is new to both her profession and her environment. Because of these two factors, Susan feels very lonely and isolated. I fear the long-term effects of this situation will cause this very capable teacher to leave the teaching profession.

I have been working with Susan for almost four months. She is a bright young lady who worked with children throughout her college years. She is a single twenty-three year old who calls North Carolina home. She has no friends or family in the area, but chose to move here to begin her teaching career. She was excited about the potential for developing new relationships.

Our school district is located in a rural setting with the closest metropolitan area located roughly sixty miles to the west. Our middle school serves approximately four hundred and fifty students in the sixth, seventh, and eighth grades. We are one of two middle schools that serve our county. We have approximately 180,000 people who reside in Brainiac, Texas. Most of the income in Brainiac is generated from agriculture and farming.

Brainiac Middle School has forty-two faculty members, and all but two of them have at least five years of teaching experience. Most of the teachers are married and are from this community. In the past, the only new teachers hired were veteran teachers recruited from surrounding counties. Our science teaching staff is small and has almost no turnover. It seems that when a teacher starts here, they never leave. In most situations this is beneficial because it helps create a family-like environment, however, in Susan's situation it leads to feelings of loneliness.

In my day-to-day dealings with Susan, she seems to have it together. She is a little overwhelmed by the responsibilities of being a new teacher, but says she is becoming more comfortable with the daily routine. I have made two observations of her teaching, and both have been positive ones. Her management strategies are not perfect, but she is willing to analyze her teaching and learn from her mistakes. She works with other teachers on an academic team and they have all pitched in to help her with her lesson plans and content area needs. She feels most overwhelmed in dealing with her special needs students. We have tried to work through some different strategies to help her meet the challenges associated with teaching these students. Susan feels welcomed by the faculty here and senses that she has a strong network of support.

As the year has progressed, I have been able to develop a close relationship with Susan. It is a relationship based on trust and support, not judgment. I have tried to make her realize that I am there to help her, not to determine whether she does a good job or a bad job. Over time, this has led her to feel comfortable speaking to me about her concerns. One afternoon during a pre-observation interview, Susan shared with me how truly lonely she was here. She talked about how nice everyone had been and how she loves teaching, but she feels that she does not really connect with anyone here. Because Susan is young and single, she cannot really identify with anyone around here except her students. We also talked about how she feels a sense of hopelessness about a change in her current situation. She is looking for young single people to develop friendships with but feels these people are not here.

My fear is that over time her loneliness will cause Susan to leave Brainiac Middle School or possibly the teaching profession. After our discussion, I thought about her situation and I can see why she feels this way. She is a recent college graduate and was a member of a sorority there. She misses those connections with people more like herself.

Since that initial conversation, we have discussed it from time to time. I have invited her to my home and tried to help her make new friends. But when all is said and done, I still sense that she is sad and lonely inside. She puts on a great "teacher face," but I think that she feels alone in a crowded room. I can only imagine how tough this feeling is to conquer on a daily basis especially with no prospects for improvement.

Questions for Reflection and Discussion?

1. How much does our personal life affect our professional life?
2. How can Susan overcome her feelings of loneliness?
3. Will time help Susan overcome these feelings?
4. If things do not change. Will Susan leave Brainiac or teaching all together?
5. What recommendations would you give Susan?

Figure 1: Sample Case

Participant Reactions to the TS^3 Experience

The participants' reactions to their experiences with the TS^3 program were collected using several different methods. Both immediately prior to and immediately after the summer course, participants completed surveys and open-ended questionnaires about their expectations and their experiences. During the semester as participants worked with their protégés, they were interviewed and asked to reflect on their experiences in the TS^3 program. The interactive television sessions were videotaped and detailed field notes of the conversations were made. The course instructors also reviewed participants postings to the bulletin board.

Using coding of these data sources, several patterns emerged. The participants generally had positive feelings about their experiences with the TS^3 program. They remarked that their interactions with other teachers throughout the state in a variety of contexts was what made their experience such a positive one. One teacher indicated that "the support of other teachers that you had throughout the whole state, some of these teachers that we worked with…I would never have met and they're phenomenal." Another expressed a similar sentiment saying, "I just really liked the camaraderie between all the teachers that we had there and the support that was there for each other."

The electronic bulletin board was integral to the development of the statewide support network. As one participant noted, "Everybody needs mentors and so we've been each others mentors and it's been good." A second participant said, " the bulletin board postings I liked….It's helpful when I do have a problem and somebody has read mine and does respond to it."

The participants felt that the development of the action plans had been a positive aspect of their participation in the summer workshop. One participant said that the action plan was helpful because of its usefulness, " I thought that was so practical and I have used it. Every time I meet with my protégé or interact with her I always go back and look at it." A second participant with 24 years of teaching experience felt that the action plan was useful because with his extensive experience, "I just assume when people walk in they know everything…it made me stop and think what do I need to cover with this person?"

Instruction and practice with observation techniques were viewed by the participants as helpful. They were able to use the techniques to give specific feedback, rather than relying on vague generalizations about the quality of the protégé's instruction. According to one participant, "one of the best ideas that I thought that I got from this summer was some of the methods that they gave us on how to look for specific things…to look at that data and learn how to analyze it…now your data really told you about how well the teacher was doing. I've been able to share a lot with my protégé."

Data sources collected over the course of teachers' participation in the TS^3 program indicated that there were several strengths for this particular mentor training program. Participants felt that the interactions with various science teachers throughout the state was one of the most important results of their participation in the TS^3 program. Various types of electronic communication enabled the participants to maintain these relationships once they returned to their own schools. Participants felt that these communications provided them with the support that that they needed to successfully assist their protégés. In addition to the positive personal aspects of completing the program, participants indicated that some of the sessions in the week-long workshop were particular useful in their work with protégés. Having the action plan that provided a concrete list of topics that mentors needed to work with protégés on guided the work of the mentors and provided a framework for them to use in their work. Training on specific data collection techniques helped mentors gain confidence with these techniques so that they could more effectively assist their protégés as they transitioned into their roles as science teachers.

Though the participants indicated that their experiences with the TS^3 program were positive, they did have suggestions for ways that the program could be improved to better meet their needs. While the participants felt this instruction in observation techniques was useful, they felt that more time should have been spent during the summer course learning observation techniques and practicing them.

Using the information generated from the interviews with program participants, changes were made to the subsequent session of TS^3 taught during the summer of 2001. More time was dedicated to the science specific skills of managing the laboratory aspect of the science classroom and converting traditional science labs to an inquiry based format. Practice with observation techniques and conferencing skills received more emphasis.

In summary, the teacher participants in the TS^3 program regarded the experience as useful to their growth as professionals. They developed positive relationships with other science teachers throughout the state and gained practical knowledge to assist them in their work with their protégés. While they enjoyed the experience, they did suggest possible strategies to improve the experience for the next cohort group.

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COMMUNITY-CONNECTED SCIENCE EDUCATION: CREATING A MUSEUM HIGH SCHOOL FOR SOUTHWESTERN VIRGINIA

Michael L. Bentley, University of Virginia

Standards-Based Curricula and Education for the Future

Jay Lemke (2000) has said that, "science and science education, as traditionally understood, may already have become either obsolete or overspecialized." The technology revolution, globalization, population growth and concomitant threats to the environment, pose new challenges to schools in educating students for democratic citizenship. This new reality is reflected in the inclusion of the 'Science in Personal and Social Perspectives' content in the National Science Education Standards (National Research Council, 1996).

Unfortunately, public high schools in Virginia are hampered in addressing these new challenges by a statewide curriculum mandated in 1995 as the Virginia Standards of Learning (Board of Education, 1995). Linda McNeil (2000) notes that one unintended outcome of the imposition of state standards on local public schools is a narrowing of learning opportunities in the school curriculum, "stifling the potential to pose counter models and to envision alternative possibilities." (p. 734) Brooks and Brooks (1999) point out that, "Educational improvement is not accomplished through administrative or legislative mandate. It is accomplished through attention to the complicated, idiosyncratic, often paradoxical, and difficult to measure nature of learning." (p. 20) Elliot Eisner (1995) also notes a negative consequence of the standards movement, viewing it as a distraction from the deeper issues of education: "It distracts us from paying attention to the importance of building a culture of schooling that is genuinely intellectual in character, that values questions and ideas at least as much as getting right answers." (p. 764) In southwestern Virginia, where I live, there has been a growing dissatisfaction with the rigidity of the state mandated curriculum and its annual high stakes testing program (Turner, 2000).

Looking for Alternative Models of Secondary Education

In 1999 a group of families in southwestern Virginia decided to organize themselves and work on a project to provide a different kind of schooling for children in the Roanoke Valley area. To address the challenges of education for democratic citizenship in the 21st century, these families have collaborated with Community School, an nK-8 private school, the Thomas Jefferson Center for Educational Design in Charlottesville, and many cultural institutions in the Roanoke area to create Community High School (www.communityhigh.net), a unique local expression of the 'museum school' concept. In 2001 the project was formally adopted by the Board of Trustees of Community School (www.communityschool.net), a non-traditional school with a 30-year history in the community.

The Museum School Concept

Museum schools are an educational innovation, with only about twenty examples in the country, only a few of which are high schools. Museum schools represent a variety of designs but all involve utilizing cultural institutions such as museums in the education of students. Most of the museum schools now operating are connected to a single museum. Our museum school project involves many of the cultural institutions in our area:

- Mill Mountain Theater,
- the Roanoke Symphony Orchestra,
- the Science Museum of Western Virginia,
- the Art Museum of Western Virginia,
- the History Museum of Western Virginia,
- the Virginia Museum of Transportation,
- Mill Mountain Zoo,
- Virginia's Explore Park,

- the Virginia Museum of Natural History (Blacksburg and Martinsville, VA)
- Opera Roanoke,
- the Roanoke Ballet,
- the National D-Day Memorial (Bedford, VA),
- the Folklife Museum and Blue Ridge Institute (Ferrum, VA),
- the Harrison Museum of African American Culture, and
- the Salem Museum.

Faculty or administrators from several higher education institutions also have been involved in the Community High School project, including Hollins University, Roanoke College, and Virginia Western Community College. Of course, students would have opportunities to study and serve in the Valley's business, legal, public safety, and medical and health communities. The Roanoke Valley is a major medical and health education center in the state.

Community School, the parent organization, currently serves a diverse population of 160 students through middle school. It is a not-for-profit institution and forty percent of Community School students receive financial aid. The Community School campus is located adjacent to Hollins University and the two institutions have had a long-standing cooperative relationship. The new school will open in September 2002 with up to 20 students. An additional class of 12-14 students will be added each year until a four-year program is established with a total student body of about 60 students. The School will be located in the Jefferson Center, a newly renovated former public high school in downtown Roanoke in the heart of the Valley's museum and cultural community. The Jefferson Center has multiple performance venues and an outstanding large auditorium and is home to a number of the Valley's cultural institutions.

The curriculum design of the new school builds upon Community School's tradition of experiential education, characterized by such features as:

- learner-centeredness
- community-connectedness
- low student to teacher ratio
- integration of environmental education in an interdisciplinary curriculum
- infusion of the visual arts, drama, movement, and music into the curriculum.

The new school will imitate other features of Community School as well. Parents have always played an important and active role in the life of Community School, helping in classrooms and in field studies, serving as trustees, and participating in a wide range of special activities. Community School's program encourages student self-confidence and self-management. The faculty and families create a nurturing and supportive learning environment. Teachers use periodic student-parent conferences instead of grades and report cards to help students take responsibility for their own progress and achievement. Every school day for nK-8 students includes time for active physical play outdoors, developing new interests and friendships, and for quiet reflection.

Student learning at Community High School will be situated in the context of the rich educational resources of the entire community. As is the practice in other pioneering museum schools, the new school's curriculum will be developed collaboratively by students, faculty and educators working in the museum/cultural community. The education program will address academics through an experiential learning approach and with many options, including project-based learning, mentorships, on-line and college courses, and community service. The school would occupy a new and unique educational niche in the Roanoke Valley, and would be of value as a model to similarly sized communities across the country.

Cutting-Edge Education

According to Sonnet Takahisa and Ron Chaluisan (1995), co-directors of the New York City Museum School, organizing and implementing a museum school is territory on the frontier of education today: "The Museum School necessarily involves a paradigm shift: requiring new organizational structures, new role definitions for teachers and museum personnel. Faculty (must have) a willingness to move in new professional directions, an interest in interdisciplinary learning, a commitment to urban education, a sense of themselves as learners, an openness to team teaching and collaborative modes of curriculum development, and a sensitivity to the school's diverse community of students and their families." (p. 24)

Community School and its partners in this project have recognized the need for facilitation of the process of creating a curriculum for the school and for special training for the staff and museum personnel. As Takahisa and Chaluisan (1995) point out, "Professional development enables staff members from two different worlds to learn from and incorporate each others' skills and perspectives, and to carry out the school's collaborative approach to curriculum development and teaching." (p. 24) Community School has enlisted expert consultation for the museum school project from Rebecca Borden, Assistant Director of the Thomas Jefferson Center for Educational Design at the University of Virginia. The TJCenter is a multidisciplinary research center created in 1996 and dedicated to the study of effective learning. The TJCenter is qualified to monitor, evaluate, and promote innovative educational designs and it promotes its findings through publications, consulting, and conferences. Before assuming the role of Assistant Director, Rebecca Borden was the director of the Museum Schools Project at the Center. She has conducted several site visits to museum schools in New York and Washington, DC, and recently published a case study of the Charter High School of Architecture and Design in Philadelphia.

Several small grants have been acquired to fund start up costs for the new school, and other grant applications are pending. Recently the Community High School Board announced the selection of Linda Thornton as Director and Josh Chapman and Brian Counihan as Program Coordinators and teachers for the new school. All have excellent academic credentials and both Linda and Josh have taught at Community School and are familiar with non-traditional, experiential education and the resources of the Roanoke Valley community. Student recruitment is underway and will continue through the spring. You are invited to follow the progress of this new museum high school on the web at http://www.communityhigh.net.

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Appendix

Museum Schools in the United States

Animal Studies/Biological Sciences Zoo Magnet
North Hollywood High School, 5231 Colfax Ave, North Hollywood, CA 91601-3097

http://www.lausd.k12.ca.us/NH_Zoo_Magnet/index.html
Partnering Institution: Los Angeles Zoo
Date started: 1981

Brent Museum Magnet Elementary School
330 3rd Street SE, Washington, DC 20003
(202) 357-1697
Partnering Institution: Smithsonian Institution
Date Started: 1996

Charles R. Drew Science Magnet School
Buffalo, NY 14211-1293
www.drew.buffalo.k12.ny.us
Date started: 1990

Children's Museum of San Deigo Elementary School
555 Union Street, San Diego, CA 92101
(619) 236-8712
http://museumschool.sandi.net/
Partnering Institution: San Diego Children's Museum (Museo de los Ninos)
Date started: 1998

Chrysalis Charter School
Redding, CA 96001
http://www.enterprise.k12.ca.us/chrysalis/
Partnering Institution: Turtle Bay Museum and Arboretum by the River.
Date started: 1996

Compton Drew Investigative Learning Center
5130 Oakland, St. Louis, MO 63110
(314) 652-9282
Partnering Institution: St. Louis Science Center

Exploris Middle School
Exploris Global Learning Center
207 E. Hargett Street, Raleigh, NC 27601
http://www.exploris.org/learn/ems/index.html
(919)821-3168
Partnering Institution: Exploris

Flagstaff Arts and Leadership Academy
3100 N. Fort Valley Road, #41, Flagstaff, AZ 86001
(520) 779-7223
http://www.fala.apscc.k12.az.us/
Partnering Institution: Museum of Northern Arizona
Opened in the fall of 1996.

Garden Vision - BF Brown School
185 Elm Street, Fitchburg, MA 01420
(978)-345-4207
Partnering Institution: Fitchburg Art Museum
Date Started: 1995

Henry Ford Academy of Manufacturing Arts & Sciences
PO Box 1148, 20900 Oakwood Boulevard, Dearborn, Michigan 48121-1148
(313) 982-6200
http://hfacademy.org/
Partnering Institution: Henry Ford Museum & Greenfield Village.
Date started: 1997

LA Museum of Science and Industry Elementary School
700 State Drive, Los Angeles, CA 90037-1295
Partnering Institution: California Science Center (A profile is being developed)
Date started: 2000.

Science Museum Magnet Elementary School
560 Concordia Ave. Saint Paul, MN 55103
651-293-5926
http://mms.stpaul.k12.mn.us/index.html
Partnering Institution: Science Museum of Minnesota

Museum School of Arts and Sciences
79 Warburton Avenue, Yonkers, NY 10701
(914) 376-8450
http://www.yonkerspublicschools.org/25.htm
Partnering Institution: Hudson River Museum

New York City Museum School
333 West 17th Street, New York, NY 10011
(212) 675-6206
Partnering Institutions: Brooklyn Museum of Art, Metropolitan Museum of Art, Jewish Museum, American Museum of Natural History, Children's Museum of Manhattan.

Stuart-Hobson Museum Magnet Middle School
410 E Street NE, Washington, DC 20002
(202) 698-4700
Partnering Institution: Smithsonian Institution Started 1997

"Zoo School": The School of Environmental Studies
12155 Johnny Cake Ridge Road, Apple Valley, MN 55124
(612) 431-8755
http://www.isd196.k12.mn.us/schools/ses/

Partnering Institution: Minnesota Zoo Date Started: 1999

Other Resources on the web

http://www.iag.net/~ksking/muslearn.html
This site has a excellent bibliography for museum education and links for other museum school partnerships.

http://www.fno.org/museum/list.html
The Grand List of School Virtual Museums

The Thomas Jefferson Center for Educational Design
Curry School of Education, University of Virginia
P.O. Box 400409, Charlottesville, VA 22904-4409
TEL 434.982.2866, FAX 434.982.4782
Website: http://www.tjced.org/museum_schools.htm

PROFESSIONAL DEVELOPMENT STRATEGIES FOR IN-SERVICE TEACHERS AND PRINCIPALS

Nihal Buldu, Indiana University
Ozgul Yilmaz, Indiana University

The goals for science teaching standards are determined in six areas in the *National Science Education Standards* (National Research Council, 1996):

1. The planning of inquiry-based science programs.
2. The actions taken to guide and facilitate student learning.
3. The assessments made of teaching and student learning.
4. The development of environments that enable students to learn science.
5. The creation of communities of science learners.
6. The planning and development of school science program. (p. 4)

Teaching science according to these standards makes teachers cope with changing science knowledge and teaching strategies. Accomplishment of this task can be attained by training teachers in accordance with these standards with the help of professional development programs. Professional development programs are catalysts for professional growth as they increase curiosity, motivation, and teachers' knowledge about subject matters. They supply best practices, new ways of thinking, and problem solving skills that empower teachers. Overall, they improve the quality of schools and prepare and support educators to help all students achieve to high standards of learning and development (Moore, 2000). However, these programs should be carried out according to standards stated in the *National Science Education Standards* (National Research Council, 1996). These standards are:

1. The learning of science content through inquiry.
2. The integration of knowledge about science with knowledge about learning, pedagogy, and students.
3. The development of the understanding and ability for lifelong learning.
4. The coherence and integration of professional development programs. (pp. 4-5)

Professional development programs should possess particular characteristics and give importance to certain strategies in order to be successful in those four areas stated in the professional development standards. Until now, many professional development activities have been implemented in different areas for different purposes. Some of these activities are innovative experiments for inservice teachers (Sandholtz, 2000) and collaborative partnerships among inservice teachers, designing course materials, and technology training (Sandholtz & Dadlez, 2000). These studies enabled researchers to come up with effective professional development programs. Knowing these findings leads developing and implementing effective professional development activities for all teachers and principals from K-12. In this study, a comprehensive review of literature is provided under the headings of professional development for in-service teachers, professional development for principals, and characteristics of the traditional and new vision of the professional development activities.

Professional Development Strategies For Teachers

According to the model developed by Guskey and Sparks (Guskey, 2000), quality of professional development programs depends on the content characteristics, process variables, and context characteristics.

Content

Content refers to what will be included in professional development activities. In this respect, professional development activities allow teachers to increase their understanding of subject matter and pedagogical principles (Guskey, 2000; Sparks & Hirsh, 1997). For instance, students may possess different cultural and educational backgrounds and have unique learning styles. Thus, today's teachers must understand how to reach students from many different backgrounds and from backgrounds different from their own. Professional development activities help teachers to learn the ways to teach according to learner differences (National Center for Educational Statistics (NCES), 1998). Teachers acquire assessment skills that will provide information for teachers to determine the effectiveness of their efforts (Sparks 2000). Research on brain, teaching, learning, leadership, and technological developments should provide valuable insights while designing the content of the professional development activities (Ganser, 2000; Reed, 2000). The instructional methods and content that teachers' experience in these activities should be consistent with what they will use in their classrooms (Sparks, 2000). For example, inquiry provides variety of learning experiences for both teachers and students. Thus, administrators need to provide opportunities to teachers to attend professional development activities in which teachers gain understanding and necessary skills about inquiry teaching to help their students to learn (Inquiry and National Education Standards, 2000). Professional development activities should also be designed to meet the needs of teachers who are at different career stages (Ganser, 2000).

Process

Process refers to how activities are planned, organized, carried, and followed up. In each step, following strategies should be considered. Teachers should be accepted as adult learners while planning professional development activities (Ganser, 2000). Professional development needs to be an ongoing process. Teachers should determine their needs and attend to new professional development activities (Ganser, 2000; McCarthy and Riley, 2000; National Staff Development Council, NPEAT, 2000). Continuous feedback and follow-up about the experiences of what the teachers gained in these professional development activities and the success of their applications in the classroom settings are important (Ganser, 2000). Principals and experienced teachers can be assigned as leaders in order to provide immediate feedback when it is necessary (NPEAT, 2000).

Interaction of teachers with their colleagues and school principals is strongly favored (Cobb, 2000; McCarthy and Riley 2000). Collaboration increases team working and allows teachers to become responsible for students learning together. Formation of teacher and principal networks among different school district teachers and universities is one of the effective ways of communication during activities by sharing their ideas, forming study groups, and finding sources of information. These networks can be formed by face to face or electronic such as the Internet communications (National Staff Development Council, NPEAT, 2000; Sparks, 2000). Professional development activities should be sustained over a long period of time (Ganser, 2000). Teachers should be taught about how they can utilize their time effectively during the workday to implement what they have learned in professional development activities in their workday.

Context

The context of professional development refers to the organization, system, and culture in which the professional development activities are implemented (Guskey, 2000). For effective professional development, teachers need to have environments where they can easily access resources and participate in activities (NCES, 1998). Continuous support in individual, collegial, and organizational level is important for achievement of optimal professional development in any context with collaborative work (Ganser, 2000). It is clear that professional development programs can be effective if there is support not only from internal but also from the external school environment. The context of professional development often extends beyond the school or districts. For example, state mandates, federal requirements, district policy, university programs, activities of business groups, and parental expectations should facilitate teachers' professional development (NPEAT, 2000).

Providing an environment for collaborative work between teachers and administrators is necessary for developing common goals and sharing ideas to increase the effectiveness of the professional development activities (National Center for Educational Statistics (NCES), 1998).

Context of professional development also includes collaboration between schools and colleges, or training institutions such as universities, local education agencies, and school districts (Ganser, 2000; Villa, Thousand, & Chapple, 1996).

Collaborative work among teachers and communities such as parents, church groups, civic associations, and business increased students' standardized test scores in Tucson's Ochoa Elementary School, which had 99% minority and 92% low-income students. Professional development programs developed by The Education and Community Change Process aimed to increase teachers' communication with community members by weekly meetings. During these meetings teachers and community members agreed on the following problems: lack of parental involvement, high rate of dropouts, lack of communication between teachers and community members, less emphasis on students' daily experiences, and peer feedback. Finally, teachers used following strategies in order to overcome these problems: multi-aged grouping, team teaching, using community as a resource, and developing alternative assessments. As a result of these efforts, student achievement increased from 24th percentile to 48th percentile (NPEAT, 2000).

Professional Development Strategies For Principals

The quality of administrative leadership defines the quality of schooling for students (Payne & Wolfson, 2000; Sparks, 2000). According to I-C-I Leadership development model, there are three complementary dimensions of leadership knowledge: interpersonal, cognitive, and intrapersonal. In terms of the interpersonal dimension, leaders need to be highly skilled in creating effective working relationships by collaboration, advocacy, group facilitation, and individual, group, and organizational communication. Moreover, they need to mobilize others for problem-solving, decision-making, strategic planning, and organizational and individual evaluation. Cognitive dimension of leadership development requires knowing and implementing effective learning and teaching practices, and facilitation of school improvement processes. Articulation of a coherent leadership philosophy that supports high student and school performance and understanding one's strengths, weaknesses, and dispositions as a leader is required for the intrapersonal dimension (Maine School Leadership Network, 2001). Professional development activities should be designed to improve principals' professional knowledge in those dimensions.

According to the National Staff Development Council (2001) and Sparks (2000), professional development activities need to be standards focused, sustained, intellectually rigorous, and embedded in the principals' workday and provide opportunity to work, discuss, and solve the problems with peers. Moreover, they are responsible for preparing skillful teachers by supporting and facilitating the participation of their teachers in professional activities (Payne & Wolfson, 2000). Interstate School Leaders Licensure Consortium Standards for School Leaders describe what is expected from school leaders. Leaders need to create and manage an effective learning environment by collaborative work with the school community in an ethical manner while understanding the larger contexts such as political, social, and cultural (Council of Chief State School Officers, 1996).

Active participation of principals to professional development programs is another aspect for professional development. It can be achieved in three ways. One way is making visits to different schools to gain a deep understanding about implementation of various professional development activities in different school contexts. Another way is working collaboratively with other principals by forming study groups and support networks. Final approach is to provide feedback and support for the development and improvement of activities (National Staff Development Council, 2001).

Characteristics Of The Traditional And New Vision Of The Professional Development Activities

Literature about professional development activities revealed the characteristics of traditional and contemporary professional development activities (Cobb, 2000; Freeston and Costa, 1998; Ganser, 2000; Guskey, 1995; McCarthy and Riley, 2000; NPEAT, 2000;Smith, 2000; Sparks, 2000). These characteristics are summarized below:

Traditional Professional Development Activities

1. There is not enough emphasis on students needs.
2. There is not enough indication of the standards usage in reference for teachers and students.
3. There is no relationship between the school improvement plans and professional development activities.
4. There is no encouragement for ongoing learning.
5. There is no cooperative working among teachers.
6. There is no feedback or follow-up related to professional development activities.
7. There is no communication among universities, state or district education departments, and schools.
8. Workshops are accepted as the basic professional development activities.
9. Single type of methodology is used during activities (too straightforward).

10. Professional development activities are too top down.

11. Professional development activities for principles are too abstract, academic or focused on managerial things and ignore instructional leadership.

Contemporary Professional Development Activities

1. Students needs are considered as the most important parameters in designing professional development activities.
2. Standards for both student learning and professional development are taken into consideration.
3. Ongoing follow-up and immediate feedback are important.
4. Multiple strategies are used during activities.
5. Different sources beyond schools are used.
6. Teachers and principles are given opportunities to go outside to learn different ideas and gain new experiences.
7. Leadership skills of teachers and principles are increased.
8. Skills for inquiry and data analysis are increased.
9. School context is considered in planning activities.
10. Adult learning is accepted as an important dimension of professional development activities and programs.
11. Professional development activities are accessible to all educators.
12. Professional development activities address diverse educational needs.
13. Professional development activities focus on individual, collegial, and organizational improvement.

14. Professional development activities strengthen teachers and principals' roles and make them active participants who can make reflections and evaluations about the activities.

Conclusion

Professional development is a catalyst for professional growth as it is increases curiosity, motivation, and educators' knowledge about their professions. It will supply best practices, new ways of thinking, and problem solving skills that empower them. Overall, it will improve the quality of schools and prepare and support educators to help all students achieve to high standards of learning and development (Moore, 2000).

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MULTIPLE PROBLEMS--MULTIPLE PERSPECTIVES: INITIATING A SCIENCE PROFESSIONAL DEVELOPMENT SCHOOL

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Contemporary efforts to prepare reformed-based science teachers involve enhancing the field-based components of preservice teacher programs and better coordinating campus-based course work with fieldwork. One example of this kind of effort involves creating partnerships between practicing science teachers and university-based teacher educators. These partnerships are based on the assumption that enhanced field-based experiences lead to the dual outcome of better preparation of prospective teachers and professional development opportunities for practicing teachers. We recently endeavored to form a partnership between a local secondary school science department and our College of Education—creating a secondary science Professional Development School [PDS]. One principle guiding our developing PDS partnership is the need to connect theory-based instruction with the real world of science teaching. In our efforts to initiate a secondary science PDS, we first searched the literature for a model and research base. Although there is a growing movement of Holmes Group partnerships (Holmes, 1990), examples of partnerships situated specifically in secondary science teaching appear largely absent. To our frustration, we found little help from the literature and few, if any, models of secondary science PDSs.

The central question we address in this paper is, what are the critical factors involved in creating a science PDS collaborative? In particular, we are interested in early efforts. To answer this question, we posed several sub questions: What conditions are needed to develop a collaboration between schools and the university that addresses disconnect between practicum experiences and University-based science teacher preparation course work? What strategies appear to fully engage public schools as equal partners in this collaboration? What are the benefits to teachers, to teacher educators, to preservice teachers, to public school students? There is a need for such as study as there is little in the literature to empirically address these questions leading to useful models of productive partnerships in science education.

The impetus for developing this collaboration was the need for the College of Education to rethink the secondary science teacher preparation program in supporting prospective teachers in learning to teach science in reformed-based ways (National Research Council, 1996). One of our goals was to enhance opportunity for preservice teachers to align with reformed-based mentors (Crawford, 1999). Simultaneously, the school district identified a need for sustained professional development for their teachers. In particular, we were driven by the question: How can we better support teachers in teaching students about scientific inquiry and the nature of science?

Our long-term goal is to develop a model of a university-school science collaborative grounded in the literature and in our experiences. This model could guide science teacher educators and prospective and practicing teachers as they develop reformed-based strategies in their classrooms. This paper describes the beginnings of our work towards developing a model professional development collaborative in science education and is part of a larger study. We articulate problems, describe solutions to the problems, and address benefits. We believe our identification of early problems and solutions will prove useful to others contemplating developing similar kinds of collaborations. We do not, however, claim at this point to provide definitive empirical evidence for the long-term effects of our professional development endeavor.

Theoretical Framework

For those who face the task of designing professional development programs, the essential elements supportive of teachers (novice and experienced) in developing reformed-based classroom practices are of paramount importance. Contemporary research on teacher change can guide university personnel and teachers in working collaboratively for mutual benefit (Krajcik, Blumenfeld, Marx, & Soloway, 1994). Earlier models of dissemination do not necessarily contribute to teachers adopting innovations. However, contemporary models that involve creating communities of learners appear viable. In the Holmes Group Model (The Holmes Group, 1990) all participants engage in a collaborative community of learners that is site -based for the purpose of extending the knowledge base through research.

Our work is clearly situated in the literature related to creating communities of learners (Lave & Wenger, 1991; Rogoff, 1994). There are varied definitions of collaboration and community of learners. One key point is that merely working together does not adequately address the issues involved in uniting two very different communities, that of a university and a school.

If we view professional development participants as learners, we can apply general sociocognitive learning concepts to professional development structure. Lave and Wenger (1991) envisioned the participants of a community of practice as master and apprentice, in which the master acclimatized the apprentice to the craft through legitimate peripheral participation in increasingly more sophisticated ways. The apprentice learns vicariously by simply being physically present to see and hear exchanges with "customers" or by engaging in less technically demanding aspects of the craft (such as the tailor's apprentice ironing garments and being exposed to the workmanship exhibited by the garment).

Not all communities and apprenticeships lead to successful learning. Lave and Wenger (1991) described a butcher apprentice system in which the old-timer community through a variety of disenfranchisement actions directed at the apprentices, ensured near-failure-to-learn by the apprentices. These apprentices were located out of the zone of vision such that they could not learn vicariously by watching what the master butcher was doing. Apprentice jobs were those jobs that did not improve their skill knowledge or expertise; in other words, apprentices were not admitted to full apprenticeship and not considered co-collaborators by the master butcher.

Several models of learning related to professional development approximate a community of practice model. Krajcik et al. (1994) suggest that inservice teachers form a collaborative association with university faculty in which the faculty provide the theoretical underpinning of practice and the teachers provide a realistic view of what works and what does not. The idea is that the university faculty and classroom teaching community meet to exchange data, ideas, and suggestions in a collaborative atmosphere. The model consists of three distinct phases—collaboration (between university faculty and in-service teachers), enactment (in-service teachers carry out theoretical ideas in the classroom), and reflection (through artifacts of practice). The model's strength is reflected in the multiple perspectives gained through the expertise of self and others as the in-service teacher reflects on practice and receives feedback via collaborative exchanges in the larger community setting from peers and university faculty. The university faculty also ground theoretical ideology through enactment and reflection (revision may be involved). The weakness of this model lies in which participants initiate the ideas for change. Critical to the success of this model requires avoiding the inevitable hierarchical structure in which teachers view university personnel as authoritative and out of touch with the real world (the Ivory Tower Syndrome). The trust that needs to be established for such a collaborative community to form necessitates at least some possibility to meet on equal terms to establish rapport and trust (Abell, 2000).

Loucks-Horsley, Hewson, Love, & Stiles (1998) describe strategies prescribed for professional development in reformed-based science teaching. These strategies include immersion in inquiry into science and mathematics; immersion into the world of scientists; curriculum implementation; curriculum replacement units; curriculum development and adaptation; action research; case discussions; examining student work and thinking, and scoring assessments; study groups; coaching and mentoring; partnerships with scientists; professional networks; workshops, institutes, courses, and seminars; technology for professional development; and developing professional developers. This model emphasizes learners--how learners learn, the construction of knowledge (considering prior and informal knowledge) and resistance to change. Collaboration and collegiality, reflection, integration of content and context are important. In other words, these professional development strategies model effective teaching strategies. Loucks-Horsley et al. (1998) argue the need for simultaneous change in the system in which teachers teach, if there is to be sustained success in teachers' professional development. Teachers need support in their schools to enable them to effect the change that will lead to restructuring schools.

It is not too difficult to find reports of successful professional development schools at the elementary level and across disciplines (e.g.Dana, 1999). However, there are few, if any, reports of the development of *science* PDS initiatives at the secondary level. In the few reports available, development of viable personal relationships appears key. One common factor is the number of years required to develop trust between the partners of these different cultures and institutions. What *are* missing in these reports are discussions of the early challenges and pitfalls.

Studying Our Journey

In order to document our efforts we audiotaped each planning meeting and work session. In addition a graduate student took extensive field notes. We transcribed each tape and used a narrative approach to analyze the data (Connelly & Clandinin, 2000). We gathered written artifacts (written work produced at work sessions, including crafted goals, mission statement, and proposed structure) and interviewed the key participants at different points. The PDS Interns wrote weekly electronic journal entries called *professional responses*. The following research questions guided our study: What are the varied perspectives of the key players in developing a professional development community of learners and what are key factors in fostering this community of learners? We used semi-structured interview questions to elicit thinking of the mentor teachers:

1. What motivated you to be involved in initiating a Science PDS?
2. How has the Science PDS enhanced preparing science teachers?
3. How has the Science PDS contributed to your own professional development?
4. What other benefits have there been to you personally?
5. What issues still need to be addressed?

Since we were fully immersed in the day-to-day operations of this endeavor, the first and third authors were able to conduct informal conversations with interns and mentors several times a week during the school year to substantiate evidence gathered from more formal interviews and journals.

Our Beginnings- A Rocky Road

As members of a newly emerging Science PDS, we reflected on lessons we learned in our fledgling two-year endeavor. One lesson is the importance of *creating spaces and places* for careful study of everyone's goals and expectations, as well as their fears and feelings of distrust. Before we began constructing our collaborative vision of a model Science PDS, we needed to carefully examine each individual participant's personal philosophy and history. Although this actually started as a painful process, it cleared the air and provided a setting for future productive discussions.

Prior to beginning this endeavor the university faculty and the local area science department had worked for ten years towards developing better connections between campus-based coursework and practicum experiences. Faculty at both institutions had worked on various projects; some more successful than others, but none sustainable due to a number of factors. The beginnings of a renewed effort to develop a Science PDS began in Spring of 2000 at a science department-wide informational meeting, initiated by the school district science coordinator, an associate principal, and two university science education faculty. We had hopes of presenting our ideas to the secondary science teachers as opportunity for all involved. The impetus for this initial meeting was the desire to improve the present field-based program in secondary science education at the university and the mutual desire to build a professional development collaborative that would benefit faculty at both institutions, prospective teachers, and students at the middle and high schools. We believed that Professional Development Schools "support the learning of prospective and beginning teachers by creating settings in which novices enter the professional practice by working with expert practitioners, enabling veteran teachers to renew their own professional development and assume new roles as mentors, university adjuncts, and teacher leaders." (Darling-Hammond, 1994, p1.) We felt we had admirable goals.

At this initial meeting we did not experience a warm reception. On the contrary, we were hit with a barrage of negative, yet sincere comments flung by the school science faculty. Several school faculty members described feelings of frustration. They felt abused, used, unappreciated, and unheard. As organizers of this meeting we suddenly felt like we were on a virtual battlefield in the middle of a verbal assault. As gruesome as this may seem, this outpouring of feelings that had accumulated over a number of years, led to several productive meetings during which interested faculty shared their personal goals and history. Before moving on to develop our ideas for a model Science PDS, we provided *physical places* for these discussions to occur. These physical spaces were nearby restaurants with funded meals and a comfortable environment. We provided *mental spaces* by allowing each person at the meeting to articulate their personal philosophies of science teacher education, their personal experiences and fears, and their visions for the PDS. Our initial talks began by putting our ideas literally on a blank slate, the blank pages of a tablet of chart paper. During a second science department-wide meeting an invited panel of Elementary Education and Language and Literacy PDS teachers and interns led by their university coordinators provided opportunity for a dynamic and hard-hitting exchange of questions and answers. Less than a year following these initial meetings, fourteen volunteer school faculty and university faculty addressed their personal philosophies, and crafted a Science PDS Mission Statement, Goals, and a Reward Structure for participating mentor teachers. The Science PDS Focus Group met in June, July, and August to continue discussions of a new science professional development school. The summer planning group consisted of one university Assistant Professor, the Science District Secondary Science Coordinator, one Middle School Science teacher, three high school Biology teachers, one high school Earth Science teacher. two high school Chemistry teachers. One high school Physics teacher; The High School Associate Principal, and three university doctoral students. A university professor of Biology attended one of the meetings to explore collaboration with the College of Science faculty and the

Focus Group. During the yearlong planning phase, the initial investment of time we spent laying the foundation for trust, appeared to sustain the newly formed and tenuous collaboration. This investment of time also appears critical for future work.

In addition to the importance of physical places and mental spaces, a second factor appeared critical in our early efforts in developing our Secondary Science PDS. This second factor involved *collaboratively crafting written artifacts.* These collaborative artifacts stemmed from our discussions. This importance lay in documenting our joint decisions and reviewing these at each meeting. Final products became the foundation for a PDS Handbook for Interns and Mentors. One key decision centered on articulating benefits for the mentor teachers. The earlier frustration exhibited by the district science department necessitated an articulation of benefits to mentor teachers. These benefits were needed to ensure sustained participation by school faculty. We literally hashed out these benefits and other products from scratch. Benefits deemed critical to the school district personnel included: office space for mentor teachers and interns; professional recognition and tangible rewards including university credits, financial compensation, and released time; and coordination of the program to ensure communication between university and mentor teachers. Some of these benefits show up in the document found in Table 1. Others we continue to work towards addressing. During our planning meetings some of the teachers and university personnel brought readings and references to share with others. But, for the most part, our PDS products were the original work of the initial planning group.

Table 1

Mentor Teacher Benefit/Reward Structure Of The School District/University Science PDS.

Level 1 1 hour of University credit (1 semester)
- 412 Intern for 1 semester
- Attend 1-2 PDS meetings OR Participate on Planning team for Friday Seminars (seminars take place the last 5 Fridays of each university semester)

Level 2 2 hours of University Credit (1 semester)
- 412 Intern for 1 semester
- Keep Journal
- Participate in regular PDS meetings

OR

Level 2 2 hours of University Credit (1 semester)
- No 412 Intern
- Member of Planning Team for Friday Seminars
- Participate in regular PDS meetings

Level 3 3 hours of University Credit (1 semester)
- 412 Intern
- Keep Journal
- Participate in regular PDS meetings
- University 597 X Course-- Readings and work on grant and/or article

Level 4 6 hours of University Credit (2 semesters)
- One PDS year-long intern
- Keep Journal both semesters
- Participate in regular PDS meetings
- University 597 X Course -- Readings and work on articles/ grant writing
- Receive professional development in clinical supervision

Products of these summer planning meetings included: 1) identification of four main functions of a PDS (preservice teacher preparation, staff development, research, and support of student learning) and a concern for balance of these four; 2) identification of critical areas for improvement of the current university science teacher education program; 3) identification of a need for greater benefits for school district mentor teachers; 4) sharing of visions for science teacher preparation; 5) development of a mission statement and goals; 6) proposal of a new structure for the university advanced methods course and practicum experience beginning in fall 2000; 7) new expectations for the methods and practicum courses; 8) granting one hour university credit for summer work; 9) proposed graduate level seminar course to further develop the PDS initiative; 10) development of enhanced communication between the university and the school district science department; and 11) commitment to continue exploration of the Science PDS Initiative. An important artifact that remains essential in communicating our ideas included a listing of the roles we envisioned for all participants. (See Table 2.)

The *early establishment of mutual goals*, a third critical factor, appeared to give momentum for positive growth. Recently members of our PDS Focus Group reviewed our initial goals, and we agreed these goals continue to guide our efforts and remain valid.

Table 2

Roles And Responsibilities Of PDS Participants

Roles/Expectations of Clinical Faculty Mentor
- Take PDS intern for a whole year (September-June)
- Review, critique, and grade selected university assignments
- Provide formal and informal feedback based on continual clinical observation
- Keep Journal both semesters
- Participate in regular PDS meetings
- Participate in PDS /University 597X graduate level course
- Receive professional development in clinical supervision
-

Roles/Expectations of Clinical Faculty Collaborator
- Various roles, depending on Level of Participation (see Benefits Structure)
- Attend PDS meetings OR Participate on Planning Team for Friday Seminars (See Benefits Structure for Level)
- Keep journal (Level 2 and 3)

Roles/Expectations of University Faculty
- Maintain communication between University and school science department
- Develop formal course instruction on methods/theory
- Grade selected assignments and serve as University instructor of record
- Set and Participate in regular PDS meetings
- Design and carry out collaborative research

Roles/Expectations of University Associate
- Make 3 clinical observations in Fall (end of Sept, Oct, Nov.).
- Make 5-7 clinical observations in Spring, (more if necessary during Jan.-April.
- Participate in regular PDS meetings.
- Assist University faculty in carrying out PDS responsibilities and instruction.
- Serve as liaison between Interns, Mentors, and University faculty
- Coordinate seminars for PDS Interns

Roles/Expectations of Interns
- Assist mentor teacher in start up and maintenance of classroom
- Take on increasing responsibility co-teaching in the classroom
- Complete all University assignments of high quality
- Plan and carry out an Inquiry-based Unit in Jan or Feb.
- Assume full responsibility for all teaching March-April
- Follow school district calendar and expectations for all staff (See faculty handbook)
- Exhibit professionalism in all aspects of program
- Communicate with Mentor, University Associate, and University Faculty

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Our Mission Statement and Goals appear below:

Mission Statement

To promote excellence in science education and science teacher preparation through the establishment of a community of science learners

Goals

1) To develop and provide multiple pathways of professional development in content and pedagogy;

2) To develop, conduct, and disseminate research related to science education;

3) To prepare prospective science teachers through innovative methods;

4) To provide appropriate recognition and resources for the PDS community;

5) To overcome obstacles in maintaining a PDS through effective, honest communication.

An important point is that prior to establishing our goals, we focused on identifying the problems. Why did we need to make changes? We asked ourselves, what are the critical areas in both our settings that need attention? Below is a summary of the issues we identified in each area: The critical areas for improvement included:

1) Importance of coordinating fieldwork and university-based coursework--"we need to get on the same sheet of music!";
2) Need for clear goals and better communication;
3) Integration of prospective teachers into a real-world setting;

4) Addressing the individual needs of mentor teachers;

5) Enhancement of teacher preparation at the university;

6) Designing an appropriate award structure for mentor teachers;

7) Meeting the research needs of the university untenured faculty;

8) Involving the school district teachers in research;

9) Involving the school district teachers in the selection and assessment of interns; and

10) Conducting professional development seminars in schools.

After a year of monthly collaborative discussions and revision of documents, we developed a PDS application for Interns, conducted interviews, and launched headlong into our first yearlong Science PDS in Fall 2001—a pilot of our vision. The *early establishment of mutual goals* appeared to give momentum for positive growth.

Where We Are Now- First Year Of Pilot

We are currently in the middle of our 1st Year Science PDS Pilot. Seven Clinical Mentor Teachers and seven Interns make up our first collaborative teams. These teams consist of the following disciplines: Mary (biology intern) and Sam (middle school teacher); Jane (biology/environmental science intern) and Don (biology and environment science teacher and district science coordinator); Jeremy (an earth and science intern) and Jason (earth and space science and environmental science teacher); Nancy (biology intern) and David (biology teacher); Miriam (biology intern) and Jake (biology teacher); Gavin (earth and space science intern) and Helen (earth and space science teacher); and Diane (chemistry intern) and Matilda (chemistry teacher). The structure we developed involved a general phasing in of responsibilities as PDS Interns began to fully embrace the complexity of the classroom. See Table 3 for the vision of this phasing in of responsibilities. Campus-based assignments are available upon request of the first author.

Beginning the second semester Interns expressed concerns about what was expected of them related to a "full load of teaching" in the second semester. We discussed the importance of interns phasing into teaching new classes and taking responsibility for teaching their Inquiry-based Unit in January or February. We anticipated Interns taking full responsibility of teaching in March and April. Yet, our PDS Model differed from the traditional student teaching model in which the student teacher "takes over" towards the end of their field experience, and the mentor teacher steps back and often *out* of the classroom. Rather, we envisioned the PDS Intern and the Mentor co-planning and co-teaching. This provided two teachers in the classroom, one of the key advantages of the PDS model. High school and middle school students benefit from having two professionals in the classroom.

We are in the middle of a messy, yet exciting first year of solving new problems as they come around the corner, while celebrating our successes. Evidence of our successes, as well as issues we continue to grapple with, are evident in the PDS Interns' written journals and the Mentor Teachers' reflections during informal and semi-structured interviews.

Perspectives of the Players

What are the varied perspectives of the key players in the development of a professional development community of learners? What is happening with the first cohort of prospective teachers? We are in the early stages of collecting and analyzing these data. However, we offer initial findings of perspectives of the Interns and the Mentor Teachers.

Table 3

Designated Teaching Class Load And Responsibilities In Which Interns Assume Increasing Responsibility As Year Progresses.

MONTH	TEACHING LOAD	THINGS TO DO	PLANNING
August		Attend Induction 8/27 and Inservice 28-30	Work with mentor
September	Teach 1 full lesson during the first few weeks	Attendance, Copying, lab prep, observations, school context (University Student Teaching Handbook)	Plan one lesson
October	1 class for one week	Attendance, Copying, lab prep, observations, school context (see Student Teaching Handbk.)	Plan and teach one week; Identify topic for Inquiry-based Unit and begin gathering resources/planning
November	2 classes for a week; Concept Understanding Interview	Design and conduct interviews (conversations)	2 classes for a week; Plan Inquiry-based Unit
December	Transition to a full day of teaching by middle of month		Plan Inquiry-based Unit
January/Feb	Plan and carry out Inquiry-based Unit	* Begin weekly seminars 1/11 and 1/2 inclusion	Philosophy of Science Teaching; Inquiry-based Unit Resource File
March/April	Full Load of teaching/Assume all primary responsibilities	Full time teaching	Full time planning Assessment Plan
May	Portfolio Due/ Grad credit class	Full time teaching	Professional Portfolio
June	Close-out of school procedures	Full time teaching	

PDS Intern Seminars meet Wednesdays after school 3 times per month (usually the 2nd, 3rd, 4th of each month (Jan, Feb, Mar, April, May) 3:45 p.m. – 6:00 p.m. Held usually at High School North or South building (room TBA). Topics will be suggested by Interns and determined by university or clinical faculty. Intern Seminars will highlight topics and include time for Interns to debrief and share experiences; there will be no additional textbook purchased, readings will be selected from journals and related to topics. Continue to use *Inquiry and the National Science Education Standards*. PDS Focus Group Faculty and Mentors will be invited to participate in various seminars

First, the experiences of the seven PDS Interns clearly can be characterized as *situated learning* (Lave & Wenger, 1991). The PDS Interns are admittedly a select group of young people, matched (through interviews and application) with their clinical faculty mentor teachers. However, the depth of thinking displayed in their weekly journals exceeded our expectations. Many of the PDS Interns' reflections portray experiences gained by working shoulder to shoulder with their mentor teachers. It became apparent during the first week of school, that their mentor teachers' introduction of them to the class as "co-teachers" bolstered the Interns' confidence levels and feelings of importance and self-worth.

> There is not an exact event that has impacted my current philosophy of science teaching, but rather a series of things. I know this may sound corny, but I learn something new everyday, even if it is something little.
> -- Intern 1- Mon, 10 Sep 2001
>
> This first week of the PDS internship has proven to be both challenging and rewarding. I was glad to have the opportunity to see what goes on behind the scenes leading up to the first day of school. It was amazing to me to see how much cleaning, organizing, and planning had to occur in order to be ready for
> -- Intern 2- Mon, 08 Sep 2001
>
> This week I have learned so much about teaching just within 4 days. Some of the things I have learned include classroom management skills, wait time, questioning skills, the teacher voice, lesson plans, and lots more. Most of these I have been taught in some kind of education class, but experiencing them in the classroom has been so beneficial.
> Intern 3- Mon, 08 Sep 2001

Second, the interns characterized their experiences as paralleling those of a "real" teacher. Their experiences appear to map on to those of an *authentic apprenticeship* similar to Lave and Wenger's (1991) master apprenticeship model in which the apprentice begins to participate through increasingly more sophisticated ways.

> My first week of school proved to be both exciting and frustrating, which is what I expected. For the first time in my life, I actually felt like a teacher. On the first day of school I had students asking ME questions. This is what really made me realize that I am indeed another teacher in the classroom in the students' eyes.
> Intern #4 Sun. 9 Sep 2001

> I learned a lot from sitting in on this meeting. I did not realize that the teachers were the main decision makers in determining the content that will be covered throughout the year. I thought the department head or the school board played a big part in this decision. It was also nice to see how the biology team worked together to accomplish their goals. There were a lot of suggestions made, and a lot of suggestion not used. This made me realize that I should not be afraid to make suggestions. I usually keep my thoughts and suggestions to myself because I am afraid that someone will not like my ideas or think that I am stupid. In closing, I learned a lot from this meeting and look forward to sitting in on additional meetings.
> Intern #2 Sun. 18 Sep 2001

> My mentor teacher and I have developed a relationship in which we are working for the benefit of the students, as well as he is teaching me the "little things" in regards to teaching.
> Intern #6 Tue. 13 Sep 2001

> ....Because of this most recent teaching experience, my mentor and I have had many conversations about teaching and learning, a true bonding experience so to speak. We created a quiz together, we compared class scores and information taught, we looked over my first full lesson plan that I wrote up, and I was able to show my true colors throughout this experience
> Intern #6 Sun. 25 Nov 2001

Third, the mentor teachers' perceptions of how the PDS impacted their own teaching involved the opportunity for their own professional growth. This professional development, however, was not the traditional kind. Traditional professional development as characterized by Garet, Porter, Desimone, et al. (2001) usually involves workshops or institutes organized by outside experts. "Reform" types of professional development often take place *in situ* and might include mentoring, coaching, and study groups. The experiences described by the mentor teachers align with what we term a *collaborative apprenticeship* model during which mutual benefit is gained by the master (mentor teacher) as well as the apprentice intern. These excerpts from mentor interviews mid-point in the first PDS year illustrate evidence for professional development mediated by the intern versus structured workshops.

> I feel like we're really working as a team. But I don't want to just think of her as my assistant. I want to think of her as a team member whose skill is at the same time in the apprentice stage. Mentor 1

> I've constantly reflected on my own teaching. As I'm helping them, you know, find the way they want to teach (the intern), so my role here as mentor teacher is not only to help them bring out their own teaching style, but to help me with my own teaching. Constantly. She and I'll stand there in the classroom and constantly talk about the lesson that's going on…where can we change things that aren't working? And we do that from period to period as we go.
> Mentor 2

More evidence of the collaborative nature of the intern-mentor relationship is illustrated by this mentor's comparison with earlier experiences with traditional student teachers.

> Now thinking about it, it's got some differences. Um, I know in the past it's been showing them what teaching's all about. Always try to show them what I can about teaching; bringing lesson plans together, classroom management, and all that stuff. Now it's really cooperative. She's (intern) comfortable enough in the classroom with what I'm trying to do, with what the lessons are trying to do, that we can collaborate more than me show her how things work. There are those teachable moments, she has them every day.
> Mentor 2

Although these findings are tentative, there appears positive movement towards an openness to change in teaching approaches. In contrast to traditional professional development provided by structured workshops or formal university coursework, the science PDS environment provides contexualized opportunity for professional development in the classroom, as the mentor and intern work together. This relates to the strategies of collective participation of groups and coherence, two reform strategies (see Garet, Porter, Desimone, Birman, & Suk Yoon, 2001).

> I want to change things, well, rethinking. I want to explore inquiry-based learning, whether or not it's useful…in general, and to me specifically. I like it on the outset. Reading more about it, as part of this PDS thing going on, and as part of it in the class I'm taking with the university assistant professor and reading a lot more about it, um, I know it certainly sounds great looking from the outside in. Now that I'm starting to get more involved in it, I'm starting to have more, not reservations, but maybe we'll talk about that more eventually, but short term goal's certainly to be more inquiry-based…" Oh, huh, I have an intern (laugh). We work together on this. She's ah, she actually knows more about it than I do. … So I'm relying on her and her knowledge base to improve mine and then working together and we actually change a lot of what I do in the classroom, especially lab-based.
>
> Mentor 2

> Being one of the first to take an intern, I, I will be able to give voice to the other teachers who are thinking about taking interns as to whether that will be a worthwhile experience or not, and so I can see myself as an advocate for it to other teachers…
>
> Mentor 3-

Discussion and Implications

This study offers our initial model and framework for a science professional development school and our insights into factors that led to progress in our collaborative. In identifying the critical factors involved in creating this secondary science PDS collaborative, we suggest that the process itself, with all participants beginning on equal footing, provided the groundwork for a productive environment. Another critical factor involved directly addressing the needs of the participants. One might ask, could another school district, another university, take our same goals and mission statement and develop a similar program? Although our goals and our framework could very well provide talking points for groups, the struggle to negotiate ideas is perhaps as important as the products themselves. This process relates to the strategy of collective participation of groups (Garet et al., 2001). Our model differs from a one-way apprenticeship model in which the mentor provides direction for her apprentice's acquisition of skills, yet gains little from the relationship. Instead, we suggest our model is a *collaborative* *apprenticeship* model, which provides mutual benefit gained by the master (mentor teacher) as well as the apprentice intern.

Many questions remain to be explored, including does this *work* or not over the long term? And, the ultimate question remains, what are the long-term effects on students in classrooms? It has been suggested that long-term, comprehensive, inquiry-based professional development is an absolute requirement for the success of standards-based reform (NRC, 2000) While this is undoubtedly true, sustaining such programs is difficult and costly. It is yet to be determined if the labor-intensive PDS effort described in this paper can be sustained over time.

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SCIENTISTS' CONCEPTIONS OF SCIENTIFIC INQUIRY: VOICES FROM THE FRONT

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Calls for reform in science instruction have occurred on several fronts (Anderson, 2001; Moore, 2001). At the same time there is a strong push for teachers to use inquiry methods of instruction (NRC 1996, 2000, and 2001; Keys & Bryan, 2001; Krajcik, et. al., 1998). The idea of teaching through inquiry has actually been around since the early 1900's (DeBoer, 1991), but implementing inquiry-based instruction into the classroom has proven to be a challenging task for teachers at all levels. It has been well established that teachers have difficulty developing their conception of inquiry (Hewson et al., 1999; NRC, 2000 and 2001). Reiff (in review) has found that many pre-service elementary teachers had difficulty conceptualizing inquiry because they had never experienced inquiry as a learner. If science teachers are expected to teach inquiry (NRC, 1996), developing a common conception of inquiry can assist them with teaching a method with which many are unfamiliar. Science educators have made significant progress in defining inquiry as a teaching method but a missing component of conceptualizing inquiry is articulating the process by which inquiry is conducted and the skills necessary to do scientific inquiries. The researchers interviewed scientists about their conceptions of scientific inquiry to enrich our understanding of not only how to teach inquiry but how to do inquiry.

Part of the confusion surrounding defining scientific inquiry is that inquiry has been associated as both a teaching method and as a method for doing science. By the 1960s, inquiry branched into separate dichotomies and had evolved into a word with separate meanings Rutherford (1964) tried to clarify this divergence by defining inquiry as a method of science termed "inquiry of content" and as a method of teaching called "inquiry of technique." Welch, Klopfer, Aikenhead, and Robin (1981) surveyed teachers' attitudes toward inquiry and discovered that teachers were using different meanings of inquiry and were unclear about the meaning. While current efforts have better defined inquiry as a teaching method, research concerning how to do inquiry provides a more holistic picture of the meaning of inquiry. Both aspects of inquiry are necessary for teachers to see that inquiry teaching methods teachers employ are providing the skills and building blocks to help their own students conduct inquiries.

We believe the challenge of implementing inquiry-based teaching into the classroom and practicing a school science that more closely resembles scientists' scientific endeavors hinges on developing a common understanding and language around the issues of scientific inquiry and inquiry-based instruction. In order to better investigate the teaching practices of scientists and their beliefs about teaching, we need to first understand scientists' conceptions of scientific inquiry. Bybee (2000) points out that there are multiple understandings regarding the term "inquiry" as applied to science education. It is not clear, however, what conception(s) academic research scientists hold regarding scientific inquiry. Yet, the idea of inquiry-based science instruction is embedded in national and state standards and needs to be incorporated into college science classroom experiences. Providing college and university science faculty with a research-based understanding of scientific inquiry may open the way to fruitful discussion regarding scientific inquiry in a classroom setting.

The National Research Council (1996) refers to scientific inquiry as "…the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work." This could be paraphrased, as 'scientific inquiry is what scientists say it is'. Accepting this rephrasing at face value we have crafted our study using a blended grounded theory approach to answer the question implied and determine what conceptions scientists have regarding the nature of scientific inquiry. We seek to develop a set of research grounded characteristics of scientific inquiry that will be a guide for our work as well as those of other science education researchers and reformers.

Methodology

Interviews with 52 science faculty members at a large midwestern research university were conducted using a semi-structured interview protocol designed to probe the subject's conceptions of scientific inquiry (Appendix A). Interviews were tape-recorded and interviewers took field notes during the interview. Together, the transcripts and field notes represent our data. Purposive sampling was used and the academic research scientists interviewed were disbursed across nine science departments (anthropology, biology, chemistry, geography, geology, medical sciences, physics, applied health, and environmental affairs). The department name is not necessarily indicative of the type of science an individual is doing. For example, atmospheric chemistry is located in the Geography department. The disciplines and subdisciplines represented by our subjects are summarized in Table 1.

Table 1
Subject Disciplines and Subdisciplines

Department	Disciplines	Subdiscipline
Biology	Zoology, Botany, Limnology, Ecology	Molecular biology, genetics, botany, limnology, ecology
Kinesiology	Environment Kinesiology Muscle physiology	Env./man interactions, Biomechanics, biochemistry
Anthropology	Physical, biological, cultural	Biomedical, functional morphology, primatology, archaeology
Environmental Affairs	Environmental Science	Applied ecology, Atmospheric chemistry, Water Resources
Chemistry	Chemistry	Physical (experimental and theoretical), inorganic, organic, analytical, biochemistry
Physics	Physics	Solid state, condensed matter, high energy
Medical Sciences		Respiratory Physiology, Dermitology, Patholoogy, Pharmacology, Medical Physiology, Cancer Biology
Geology		Sentimentary, Geochemical, Paleotology, Geochemistry, Structural
Geography		Atmospheric science, Economics, Land Use/GIS, Developmental

We introduced the interview by letting subjects know that we were interested in their own understanding regarding scientific inquiry and that, therefore, there were no “wrong answers”. Our first question was “what is your definition of scientific inquiry?” This direct question served as a way to focus our subject's attention on the issue and to get an insight into their broadest and most general initial conception of scientific inquiry. We expected that by the end of the interview many subjects would be more comfortable talking about scientific inquiry, would have found their own voice, and might therefore amend the initial response. Subjects were reassured that they would have the chance to revise or alter their answer to this first question at the end of the interview.

The method of analysis used for this study was grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1990), which is a qualitative method that uses naturalistic techniques. Using these techniques, relationships emerge that are provisionally tested to further define boundaries and generalizability. The emergent categories, relationships, hypotheses, assertions, and theory are grounded in the data and are used to support, refute, add, or further define existing theory in the literature. Consistent with this methodology, the data were collected and coded systematically and categories and concepts began to emerge.

After conducting the interviews, we independently looked for patterns and connections in the science faculty members' responses to each of the eight interview questions. We noticed that concepts and descriptions from one interview would correspond to similar concepts in another interview. Descriptions emerged consistent with other science faculty members' responses in the interviews. If different science faculty members mentioned a concept more than once, we included that concept on a list of descriptors of scientific inquiry. These concepts resulted in a tally sheet that was used to identify when science faculty members mentioned the same or similar concepts. We compared our independent tally sheets and agreed on a single list of concepts with a consistent understanding among us as to how to classify items. We then independently read through the interviews a second time. When a concept was mentioned, the appropriate box on the tally sheet received a check mark. For example, several scientists mentioned "meticulous" as an important characteristic of an investigator in conducting scientific inquiry investigations. In other instances, descriptions such as "detail oriented" and "a careful recorder of data" were also included under the concept "meticulous".

Within each of the nine departments, we used tally sheets for individual faculty members. Each department's responses were pooled together to represent the frequency of concepts mentioned. The results from each science department were used to compare science departments to see if patterns of frequency developed. We accounted for validity by cross checking the tally results of each interview with the results of another member of the research team. When a discrepancy occurred, the results were discussed until a mutual agreement could be made (Tobin, 2000). In such cases, often one member had overlooked the concept in the interview.

Researcher Expectations

As a group of researchers we came to this study with certain expectations (Tobin, 2000). First, we expected to be able to identify a set of characteristics of scientific inquiry depicting scientific inquiry investigations. Second, we expected that there would be more than one conception of scientific inquiry with different sets of characteristics. Third, we expected that scientists from different disciplines would have unique conceptions of scientific inquiry. We asked our subjects for information about how they identified their field and subdiscipline (Table 1). Generally, however, we expected continuity of responses within science departments and discontinuity between most science departments.

One of the initial goals for this project was to describe groups of scientists that shared a similar conception of scientific inquiry. It was our initial belief that by clarifying the set of definitions of scientific inquiry, and then identifying which sets of scientists held which conception, reformers might be able to be more effective in engaging specific faculty groups in discussions regarding bringing inquiry-based instruction into college science classrooms.

Table 2

Frequency of concepts in describing characteristics of the investigator and the investigation

Investigator		Investigation	
Make connections	33	Literature-based	38
Connected to other disciplines	29	Testable question	34
Focus on process	26	Meaningful question	24
Analytical	24	Repeatable	16
Persistant	20	Multiple Methods	15
Critical thinker	19	Systematic	15
Flexible/Openminded	18	Verifiable	13
Problem solving	18	Scientific Method	12
Observant	17	Serendipidy	8
Curious	17	Falsifiable	4
Meticulous	17		
Logical	17		
Decision maker	17		
Willingness to be wrong	17		
Collaborative	16		
Communicator	15		
Objective	14		
Creative	13		
Disciplined	12		
Skeptical	10		
Wired differently	9		
Think outside box	9		
Manual skills	8		
Patient	7		
Active searcher	7		
Organized	7		
Moral	5		
Enthusiasm	4		

Results and Discussion

We found that some of the scientists interviewed shared our expectation that scientific inquiry is understood differently by different groups of scientists. Many interviewees prefaced their response by informing the interviewer that they could only speak for themselves because other scientists would have a quite different perspective. In spite of the claims that they practiced science differently from scientists in other departments/field/perspectives, we found no significant difference among the characteristics associated with scientific inquiry. In analyzing the interviews, numerous similarities emerged instead of differences regarding how scientists believe they approach and do science. Our study quickly developed a focus on the commonalities that exist among disciplines and pulls these ideas together to enrich our understanding of scientists' conception of scientific inquiry.

We have arranged our results into three broad areas: The investigator, the investigation, and qualities of scientific inquiry. The characteristics of each of these areas are summarized in Table 2 (see previous page).

The Investigator

A key outcome from our study is a set of characteristics required of science investigators (Table 2). These characteristics have implications for the way in which teachers—both at the college and pre-college levels—present scientific inquiry to students. The most commonly mentioned characteristics of the investigator include the ability to make connections, connect different disciplines, focus on the process of the investigation, and have analytical skills. We found that 33 out of the 52 science faculty members identified "*making connections*" as an important skill for an investigator and, thus, became the most frequently mentioned description of what makes a good scientist.

Making connections refers to the ability to take pieces of information and to be able to look for patterns and connections within the data. In this case, the scientist is trying to make sense of the data. A scientist who is able to make connections has the ability to focus on the details of an investigation as well as to see the implications of the study and how the pieces fit together. The scientist must be able to keep track of details as well as be able to see the larger picture. A geographer used the metaphor "seeing the forest through the trees" to describe this skill set. The trees represent isolated facts of information, often disconnected, while the forest serves to connect the pieces of information into a living, breathing system.

Another scientist compared the process of making connections or synthesizing information, as other scientists described it, to assembling a puzzle. The scientist must try to figure out how the data fit together or how the pieces of a puzzle should be arranged. Through the process of making connections, eventually, a picture emerges that gives new meaning to the individual pieces.

Scientists identified the ability to make connections or to see patterns as valuable and characteristic of good scientists.

> The best scientists, I think, see connections where no one else saw. Most great discoveries are really new connections, transferring some knowledge to another situation.
>
> The heart of the matter is identifying patterns. Some people have it, other people don't. There is an enormous amount of information out there. Most of it irrelevant but guys like Watson and Crick were able to see the pattern.

The ability to synthesize information, to see things that others have not seen, to look at all possibilities, to keep track of the details of an investigation but also to see the larger picture are all attributes of making connections and are paramount in describing what makes a good scientist.

Another valued characteristic of an investigator is to be able to "*connect disciplines*". For example, a geologist described how techniques used in biology or chemistry could also be applied to a geology study. As might have been expected, math, statistics, and technical skills were also identified as benefiting the investigator. Knowing fields of study other than one's own seemed to enhance an investigator's ability to utilize resources and methods from different disciplines that could enhance a study.

Scientists also stressed the importance of writing skills, pointing to the importance of effectively communicating scientific ideas and discoveries.

> I think that anyone that gets into science as a whole and doesn't understand that they're also becoming a writer is fooling themselves, because a large part of the success in science relates directly to one's ability to convey that information to other people and that is a huge part of doing science. So I think you have to be a good writer.

A good scientist has the ability to "*focus on the process*" of an investigation without jumping to conclusions. Several scientists referred to Einstein and Newton as examples of scientists who spent time on the process of an investigation and not just the end result. "Einstein spent many years developing his ideas, they didn't just happen overnight." Another scientist in the same department explained how Newton was working with the building blocks that led to his result. He said the same is true with Einstein, "he didn't just wake up and say, 'Oh, $E=mc^2$'."

A geologist compared the process of scientific inquiry with that of putting together a mosaic. Sometimes in the process of making a mosaic, an artist or a scientist has to keep track of the individual building blocks while making the picture. In the process of the investigation, the scientist might find pieces of information that do not fit with the evidence. This information should not be discarded but may be useful in planning additional inquiry investigations. As one anthropologist explained,

> To me, it's very open ended, and the question that set out to investigate, in the course of your research may not turn out to be the most fruitful line of inquiry. That to me is a very strong feature of my work. It's often gone in different directions than what I originally intended. You have to be open to that, and not so invested in your ideas.

By focusing on the process of an investigation, the investigator can be more receptive to serendipitous moments. These flashes of insight can come day or night. Scientists stressed that science does not take place just in the laboratory. Reflecting and analyzing findings can happen in the shower or in bed. The investigator who is focused on the process of the investigation and not just on the end result will be more receptive to experiencing these realizations.

> The interesting experiments are always serendipity, I think. They come in the middle of doing something. If you aren't doing anything, you can't make discoveries.

About half of the science faculty members described the ability to stay focused on the process of investigation as a desirable characteristic of an investigator.

> It's really trying to get people to enjoy the process of learning not just the answer. Same with my students, try to enjoy the process of getting a degree, not just obtaining one.

This rush to get the right answer can mislead students into thinking that science has a right or wrong answer when, in fact, scientists described the process of finding evidence contrary to the expectation as leading to important discoveries. A scientist from the geology department explained, "A lot of scientific breakthroughs start when you find an exception to those supposed rules." This "*willingness to be wrong*" is an important feature of the inquiry investigator. This willingness to be wrong is described by Harding and Hare (2000) as open-minded realism. Surprising results should not be discarded because they can add to the existing evidence, lead the investigator in another direction, or can spark another investigation.

> I get really frustrated with people, including close associates, who set up what they want it to come out to. And I'm proud to say that most of my research hasn't come near to what I thought it would be…I like wrong answers.

The willingness to be wrong also was associated with personality traits and attitudes such as "having a certain amount of guts, the courage to go into something where there's a high probability that it won't work." The willingness to admit that the equipment failed or that the hypothesis was not supported leaves the possibility for unexpected discoveries. The willingness to be wrong is part of the process of conducting an investigation.

> Wrong hypothesis. That's the way it goes. Science doesn't guarantee that you're going to get the right answer. In fact, it almost guarantees that you will occasionally get wrong answers, sometimes more frequently than you expect. So much of what science is, [as] we do it in the laboratory, consists of getting the wrong answers because that's how we learn and refine our approach.

The ability to make connections, to connect disciplines, and to focus on the process was the most commonly mentioned characteristics of the investigator. In addition to these skills necessary to do scientific inquiry, science faculty members also discussed personality traits desirable of an investigator. These traits included persistence, open-mindedness, critical thinking, and curiosity.

Persistence was described as "the ability to concentrate over long periods of time," "attention to drudgery", "being disciplined," "the ability to tolerate frustration," and to have a "thick skin" or "emotional resilience" after being turned down for a grant the third time. When asked what are the skills needed to do scientific inquiry, one physicist responded, "Persistence, love of what you do, which leads to more persistence, and more persistence."

Genuine scientific inquiry can be frustrating. Equipment fails to work properly, procedures must be refined by trial and error, and many variables must be controlled. Inquiry in classroom settings often contains these and other sources of frustration (unfamiliarity with technique and/or materials, for example). What is not evident in most K-16 scientific inquiry is the solution to these circumstances used by real scientists: persistence. When scientists get unexpected or strange results or results indicate a mistake has been made, the scientists takes the time to rethink their investigation, make changes, and repeat the effort. Students in K-16 inquiry investigations rarely have the opportunity for this important reflection, change, re-do process. Yet, this develops as a key trait for investigators who persist with their inquiry and do not easily give up on an active investigation.

To think critically is another important attribute of a good scientist. Critical thinking is a trait needed to examine problems and to question findings. Scientific inquiry is viewed as a way to teach critical thinking skills (NRC, p.23). Ultimately, as one geologist explained, "What we are trying to do is teach people how to think." An anthropologist viewed critical thinking skills as applying holistically to many forms of expression.

> But having them [students] critically observe, critically write, critically express themselves, all of that is what, I think, is good science. I think that high school teachers tend to steer students away from some of that critically examining positions for whatever reasons and when they come to college they are very unfamiliar, very unprepared to begin to question, to begin to evaluate information for what it is and what it might not be.

Some scientists described children as scientists because of their strong sense of curiosity. In several instances, the scientists cited examples of their own children as little scientists who were full of questions. One medical scientist explained, "Young children, during the first three years of life have a natural curiosity; their brain goes in ten different directions. They ask questions we never think of." One biologist went as far to claim "the most scientific inquiries in anybody's life are undoubtedly those where they are three years old or two years old." This scientist went on to describe how,

> Children start out as scientists. We beat it out of them. How did they learn to walk, to run, to ride a bicycle? All of these, in fact, are inquiries into the forces of nature. Most people start out as curious. Somehow that curiosity disappears over time.

Another scientist reflected, "The difference between scientists and normal people is that as people mature, they lose that childish curiosity. Scientists, on the other hand, don't. The unfortunate thing is that they maintain all other childhood traits as well as curiosity."

Some scientists considered creativity as an important characteristic of an investigator. A scientist from the anthropology department compared cello playing and writing poetry to the creative process in science. She explained that playing the cello is not just playing the notes but it's about, "putting something of your own, yourself there." In writing poetry, one uses creativity to decide what structure or format will be used in much the same way a scientist decides which method to approach a problem. Another scientist viewed creativity as a means for advancing scientific thinking.

> If you don't have creativity and an imagination and a willingness to try new things or think outside of the box or however you want to put that, then all you're doing is repeating what other people have done and you're not necessarily going to make major new discoveries.

Through questions in our interview such as "what are the characteristics of scientific inquiry" (Appendix A), scientists elaborated on what makes a successful scientist. Defining characteristics of a good scientist such as the ability to make connections, to connect different disciplines, to focus on the process of an investigation, to have critical and analytical thinking skills can help teachers to identify the many qualities of scientists and help students with the skills to carry out scientific inquiry investigations. Some of these characteristics of scientists may be unfamiliar to students who have images of scientists working in a lab with frizzy hair and glasses (Barnum, 1997). Some of the personality traits of scientists such as curiosity, persistence, creativity, and among others enhance the image of a scientist to one that seems more real. If students can relate to some of these qualities then they might consider themselves as scientists using similar skills to do scientific inquiry.

The Investigation

Scientists in our study also identified key characteristics of good scientific investigations (Table 2). The most important aspect of an investigation is that it is literature based. This result is consistent with Magnusson et al. (2000) in their exploration of the development of scientific reasoning through guided inquiry. To the scientists in our study, an investigation is only worthwhile—it is only truly a scientific inquiry—when crossing the boundary from the known to the unknown. A great deal of effort is expected from investigators to review and understand the published literature surrounding their question. From this reading, investigators are able to refine their central question to one that will address an exploration into the unknown. An anthropologist pointed out,

> A good bit of science is simply knowing and keeping track of where the knowledge base is. I think scientific review, literature review if you will, is the test of your credentials because what a good reviewer will then be able to detect is whether you are at that border, whether you are going to contribute anything beyond what is already known.

Along with this sense of the border, academic research scientists also view scientific inquiry as an accumulative process in which "we base our stuff on something that has been known and try to do something new based on the body of knowledge that already exists." A secondary benefit provided by an understanding of the literature is guidance regarding the details of the investigation. Scientists need to know what has been done and how it was done. This information can help a scientist develop a meaningful inquiry. An environmental scientist said,

> I studied the literature so instead of reinventing the wheel I was looking at if people had already answered that question. You will find that people have already answered other questions that are related so it gives you ideas about how to approach the study.

It is at the border between the known and the unknown where new knowledge is attained and the process of scientific inquiry is the bridge connecting the known with the unknown. The focus on pushing back the border is very strong and it is through understanding the literature that one can most easily identify questions of interest to the discipline. Part of moving from the known to the unknown is "starting with the certainty and then moving to the uncertainty."

A physicist cautioned that teachers and students, who may be uncomfortable with not knowing the answers, might be reluctant to ask questions. Some teachers may not encourage questions because he/she doesn't know the answer.

> If teachers just learn that asking questions without knowing the answers is wonderful. Kids love it and you could be doing it in the first grade. Why not have teachers help kids ask questions? That's scientific inquiry right there.

As mentioned earlier, knowing the literature is important to a proper scientific investigation. It is considered instrumental in developing good and interesting questions in the field. Scientists who are well informed as to what is known can stretch the boundary between the known and the unknown.

> It was hard to get the point where I could ask an original question, where I felt I knew enough to ask a good question. It takes awhile before you know the literature. I felt I could ask original questions because I knew what had been done.

Helping students to develop good questions seemed to be equated with the terms a *testable* and *meaningful* question. Scientists mentioned the importance of developing a good question as driving the investigation. This can take the form of a hypothesis but one scientist scoffed at the traditional hypothesis statement.

> The way that many of the textbooks force people to teach and the way my son was taught in schools is you must have a hypothesis, you must write down your predictions. It's absolute gibberish. That doesn't make sense. That's not science. So the answer is you have to have a question.

What is considered more valuable than stating a hypothesis is deriving good questions. As a medical scientist claimed, "The hardest thing to do is to teach students the ability to ask the right questions." Scientists used the term *meaningful* to describe questions that contribute new knowledge to the field of study or those that would lead to interesting results. *Testable* questions are those for which scientists have (or can imagine having) the resources to carry out the study.

To ask, 'What is the meaning of life?' is not considered a good question because it is not testable. The term "falsifiability" also emerged when describing a testable question. Falsifiability refers to whether a question is capable of being proven or disproven; that is, the question or the hypothesis/prediction can be proven false. The example given by an environmental scientist is the question 'What will happen if salt is placed in water?' and the prediction is that the salt will dissolve in water. Then this statement is falsifiable because it is possible to prove or disprove the whether the salt will dissolve in the water.

> Science, as I have been taught and as I teach and as I practice, is something that limits itself to those areas in which it is possible to know when you are wrong. That's the nature of falsifiability and it's really what sort of sets the limits for what scientists are willing to blunder around in.

In inquiry investigations, teaching students to question contrasts with the approach of telling students facts. Telling students facts is teaching them what we already know. If we teach students to question and provide them with the tools to do scientific inquiry, students will be better able to cross the border between the known and the unknown and contribute to scientific understandings. Two scientists spoke with distain about teaching facts:

> You are saying, here's a fact, here's the procedure you can use to demonstrate to yourself that the fact is true. That's not science. That's history. Science is finding out what we don't know.

And,

> I mean simply telling people this is the name of this, this, this, this, doesn't really strike me as science. But having students make inferences about what happens when you cross this one with this one strikes me as having something to do with science.

Our subjects conceptualized the process by which scientists accomplish scientific inquiry as a set of interactive stages. The fact that these scientists framed their work in a common conception of the investigation process was a surprise. Based on our data of scientists' conceptions of the scientific method, however, it is readily apparent that the commonly used version of the 'scientific method' found in science textbooks needs to be revised and restated to fit a broader view of the way science is done. Several science textbooks surveyed depicted a linear progression of conducting science where the end result is either a theory or a law. Many scientists interviewed indicated that the process of conducting a scientific investigation is not linear but iterative. It is one where questions are asked along the way and emphasis is given to the process, not the end result.

> We all practice science to a degree, whether we are driving our cars and eating our dinners…I think there are moments at which we are in fact presented with alternatives and dilemmas and we proceed to go through some decision making. Now will they always follow along a scientific protocol or step-by-step methodology? I don't think so but then science doesn't either. Hypothesis, methodology, testing results, conclusions. Things don't move around in quite that progression; things get bumped around a bit and, I think, in everyday life I think it's the same way.

Thus, scientific inquiry does not follow in a linear path where each stage is completed before moving to the next stage. Scientists described the process of investigation as messier with stages that do not necessarily follow a particular order. For our subjects, the process of conducting a scientific inquiry can be viewed as a set of stages that answer and generate questions. These questions and their answers are the force that moves the investigation forward. In this model, scientists have the flexibility to generate questions along each stage and to revisit previous stages whenever needed. This fluid approach better portrays how science is practiced among scientists than the standard "check-list" found in textbooks.

Qualities of Scientific Inquiry

Scientific inquiry is fueled by questions, which drive the investigation.

The importance scientists place on questions in driving the scientific investigation is also evident from our data. Scientific inquiry is described as concerned with "asking questions in hopes of learning the next question." Questions are at the heart of any scientific investigation and serve to fuel an investigation. Lederman (1998) defines scientific inquiry as "the systematic set of approaches used by scientists in an effort to answer their questions of interest." The scientists in our study reinforce this view. Questions serve as the foundation for the bridge of knowledge to be built. A geographer echoed the central role of questions,

> You should question everything. Question, question, question. Why, why, why? If nothing else, science is important for that. It keeps everybody on his or her toes. If there were more scientists, we would be on our toes. We are not on our toes.

Scientific inquiry is a process that focuses on the investigation and not the end result.

An important feature of inquiry investigations is staying focused on the process of an investigation. Scientists who are primarily concerned with proving a hypothesis may overlook data in the rush to communicate findings to peers. An anthropologist described, "Inquiry is what keeps you from jumping to conclusions." The process of conducting an inquiry investigation involves forming questions, reviewing the literature, articulating an expectation, designing and conducting the study, interpreting and reflecting on the results, and communicating the findings. By following these stages with the ability to repeat previous stages better ensures that investigations are thorough and contain higher levels of internal validity.

Scientists emphasized the importance of helping students to focus on the process of an investigation and not just on getting the right answer. Scientists may take many months or years to reach conclusions and then may decide to repeat one of the earlier stages. If students are primarily concerned with getting an answer, they may associate science as a linear progression of steps that leads directly to a theory. As a medical scientist explained:

> It's really about trying to get people to enjoy the process of learning and not just the answer. Same with my students, try to enjoy the process of getting a degree, not just obtaining one.

Scientific inquiry is an approach used in problem solving.

Some scientists related scientific inquiry to solving problems in their everyday lives. In fact, 39 out of 52 scientists connected inquiry with activities outside of the realm of science. "Let me put it this way, I can't think of many things that scientific inquiry doesn't one way or another play a role in a person's life. They are doing it but they don't know it's scientific inquiry." Trying to figure out why the car won't start, why an appliance has stopped working, or how to get the lights to come on involves using skills in inquiry to help find solutions to these problems.

People can approach and solve problems in ways similar to scientists solving a scientific problem. "I think science is just day to day problem solving, maybe in a different arena but the same process." Some scientists compared the act of farming or gardening to scientific inquiry. For example, a farmer is questioning the type of fertilizer that is best suited for planting a particular crop. Similar to a scientist, the farmer may ask experts about the problem or review information concerning different types of fertilizer and then designing an experiment to test the hypothesis. If further studies are needed, the farmer may repeat any of the stages mentioned earlier and redesign the experiment using different controls. The farmer can then decide to communicate the findings to his peers (farmers) or to the community. Scientific inquiry results in enhancing understanding of problems and in coming up with solutions to these problems.

Scientific inquiry is a natural way of thinking.

Scientists stressed that people do inquiry in their everyday lives without realizing it. Some scientists went so far as to insist that inquiry is a part of what it means to be human and that humans could not survive without it. The skills of identifying a problem, forming a question, searching for an answer, and making improvements are scientific skills that can be applied in everyday life. In fact, without these skills, some scientists insisted we would die. "You've been doing scientific inquiry since you were old enough to recognize patterns; you can't stay alive without doing it."

Scientific inquiry involves skills children possess.

A large group of scientists (38 of 52) indicated that the skills necessary to do scientific inquiry should be presented to children at a young age. When asked what age should people do scientific inquiry, a chemist responded, "Zero, I mean immediately because one of the keys is asking questions." Several scientists described how developing skills in scientific inquiry could start at an early age, even two and three year olds. Perhaps children would not be able to synthesize the information or analyze the results but the fundamental skills involved in scientific investigations such as making observations and conducting a test can be practiced at an early age. Even though scientific inquiry is considered a natural process of thinking and approaching the world, scientists recognized that children could develop the skills and learn about the tools necessary to carry out investigations. A natural curiosity about the world may be innate but in order to put the building blocks together to see the bigger picture takes analytical skills that may take time to develop. Some people do not move beyond the basic level of making observations. A chemist explained,

> I think it [scientific inquiry] starts at three years old. It's just different. It changes so at the earliest stage is probably purely observational. Let's categorize butterflies and let's look at the flowers and the shape of things. I think that is the earliest stage. It's purely observational, then classification but then, of course, I think it shouldn't stop at that stage. I think that for too many people that's what science is and that's a little tragic.

Scientists agreed that scientific inquiry skills could be refined with children. A geologist described skills such as observation occurring within a structured experiment beginning in kindergarten.

> You can say to a small child, let's see what animals come to the door if we put a can of tuna there. Let's see what animals come to our door if we put a banana out there. What about other things like Jell-O? A kindergartener can discover that raccoons eat anything, ants eat Jell-O and it's inquiry-based. It's what happens if…?

A geologist agreed that scientific inquiry could start with children because they are naturally curious. Perhaps they wouldn't be at the point to synthesize information or to make connections but children can start learning about the building blocks and then put the blocks together when they get older. A chemist elucidates this point "…but you can start with the first elements, say observation and then as they get older, you can build on some of the other elements."

Though children are not contributing original pieces of work, they are still working on the building blocks to do scientific inquiry. Through experience, these blocks can be constructed into an original piece of work.

> If you define science as a set of questions and answers tied together with logic than a toddler could do it but that's a very simple building block of scientific inquiry. If you define science as producing original work that needs to be founded on previous knowledge to identify what is original then it depends on your definition of inquiry. I think they're both right…the second one was more scientific work that leads to original work and the first one was sort of a building block on how to do scientific inquiry.

The scientists felt that everyone has questions and that scientific inquiry is a very effective process to get answers to many questions. Thus, there was a strong theme to provide people, especially children, with the skills and habits of mind to conduct scientific inquiry. Almost all the scientists felt that it was very important for everyone to understand the process of scientific inquiry. "If people understand more about science instead of being afraid of it then they would discover how to use scientific discovery wisely." Another scientist responded, "How do people make progress? How do we get where we are? There are lots of people that ask questions." Thus, asking questions builds on the knowledge base and progresses science from the unknown to the known (see below).

Scientific inquiry is the bridge that takes us from the known to the unknown.

Questions are the driving force required to cross this bridge. These are the questions that require us to learn what is known and then develop new knowledge in order to gain an answer. The new understanding will provide the basis for further questions. The answers to these questions refine our understanding of the world and the way it works. Here, then, is a connection between scientists' conceptions of scientific inquiry and their conception of the nature of science. For example, the scientists in our study understand that the "known" is not static. That is, science understanding is mutable and changes with time. New evidence and new models improve our understanding and supplant or adjust earlier ideas. Scientific inquiry provides a continual process of asking questions that challenge the existing knowledge base. Summing up this idea, one scientist informs the class he teachers as the following:

> What I'm going to tell you in this class are things that I think are true. I wouldn't lie to you intentionally. But, you know, twenty years from now you may look back on this class and say that everything I told you was garbage. Hey, if that is the case, then I'm sorry but that is the nature of science. My job is to train my students to prove me wrong. Of all people, my students shouldn't trust anything I say.

The idea of science extending the borders of the known into the unknown was viewed as being the key defining issue for good science. However, scientists also felt that extending *personal* knowledge and understanding of the world is also important. In particular, the role of children in taking an approach to knowing that develops the skills and habits of mind inherent in scientists' conception of scientific inquiry was strongly encouraged almost all of our subjects. They felt that children's exploration could be a model for genuine scientific inquiry, where the community's knowledge and understanding is increased. The focus of children in pushing back their personal borders between the known and the unknown can be aided with the tools and techniques of science.

Implications

This study provides an insight into scientists' beliefs regarding scientific inquiry; that is what scientists believe they do and the general approach they believe they use. It adds to the literature regarding the nature of science as it applies to the issue of scientific inquiry. Lederman (1998) indicates that the conventional wisdom is that approaches to scientific inquiry vary widely within and across scientific disciplines and fields. Our results suggest that the approach to scientific inquiry is common to this group of scientists regardless of discipline. The tools and techniques that scientists' use in a particular study will, of course, vary with the goals of the study.

The set of characteristics for scientific inquiry determined in this study support those listed in the National Standards (p. 23):

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; communicating the results. Inquiry requires a clarification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.

Additionally, we define the key goal of scientific inquiry as pushing back the border between the known and the unknown. Moreover, that scientific inquiry can be viewed through the lens of six over-arching qualities of scientific inquiry. Scientific inquiry

1. is fueled by questions, which drive the investigation.
2. is a process which focuses on the investigation and not the end result.
3. is an approach used in problem solving.
4. is a natural way of thinking.
5. involves skills children possess.
6. is the bridge that connects the known to the unknown.

These six qualities are gathered together into a conceptual model for scientific inquiry that is consistent across disciplines. This model contains the elements identified in the National Standards quote above, but captures these and other elements into distinct stages that can be visited and revisited as often as necessary in the course of a scientific inquiry.

An implication of this conceptual model of scientific inquiry is that teachers of science need to expand on the step-wise version of a scientific method as outlined in textbooks. Moreover, that reflection is an important part of a scientific inquiry. Students need to be presented with the opportunity to reflect on results critically with the goal of improving their experiment, rather than simply noting that they achieved a "right" or "wrong" result. Scientists rarely categorized results of their inquiries as correct or incorrect. Rather, they looked on their results as confirming their expectations or providing information to improve either their question, their model or experiment, or their understanding of the topic. Scientists in our study indicated that they work hard at thinking about their ideas and results, examining and re-examining them many times.

This implies that research is needed to explore the value and practice that university scientists place on modeling scientific inquiry in their college science courses (Gess-Newsome, et. al., in review; Southerland, Gess-Newsome, & Johnston, in review). How many college science courses, provide opportunities to do experiments, evaluate the results, and repeat or extend the experiments as necessary? The set piece right/wrong sort of laboratory is easy to grade, but not indicative of what scientists believe they do in their own inquiry. DeBoer (p. 192) points out that:

> It has long been a goal of science educators to develop in students ways of thinking that mirrored the way scientists think about the natural world. Development of these intellectual skills was important for two reasons. First, anyone who might become a scientist had to learn how to think like a scientist, and second, for those who would not become scientists, scientific thinking provided an effective way of dealing with their everyday world.

Conclusion

The combination of responses in defining scientific inquiry from nine science departments greatly enriches our understanding of scientific inquiry and provides intriguing insights into how scientists believe they do science. Scientists' conceptions of scientific inquiry did not seem to be influenced by the department to which they belonged. Instead, scientists across disciplines shared a common understanding of scientific inquiry that is not often elucidated to the general public. The most salient differences among our set of scientists appears to be the types of question scientists ask, the tools used to resolve the question, and the styles expected for formal reporting of the outcome. The general process of investigating their inquiries was consistent across all disciplines.

A key feature of scientific inquiry, as described by they scientists in our study, is a focus on scientific inquiry as a process. The process of scientific inquiry is fueled by questions, the answers to which provide a bridge between the known and the unknown. Moreover the process of scientific inquiry is grounded in appreciating two key aspects of the nature of science. These are that scientific knowledge builds upon and extends previous knowledge. That is, that scientific knowledge is accumulative. Along with this, that scientific knowledge is mutable and changes over time as the results of scientific inquiries are obtained.

This study is limited in that it examines scientists' conceptions of scientific inquiry and not their actual practice. Avenues of future research would include developing a better understanding of scientists' actual practice and whether or how it relates to the conceptual model provided here. Many of the scientists in this study indicated their feeling that young people should be involved in scientific inquiry in classroom or course settings. This also provides an important avenue for research and instructional development. Do scientists take their conception of scientific inquiry into classroom settings? An exploration of many issues raised by this question would help the science educators and scientists interested in science education reform to be more effective in their efforts.

The emerging patterns from our study provide an interesting array of possibilities and directions that lead us to further our understanding of scientific inquiry. Through this understanding, it is hoped that we can improve science education for students at all levels. A common conception of scientific inquiry is essential to aligning teaching practices with the National Science Education Standards. If teachers do not understand inquiry or have never been modeled scientific inquiry then they are unlikely to inculcate students with the skills and practice to conduct inquiry investigations. Scientists can help to better define scientific inquiry so that teaching inquiry really becomes the standard.

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Appendix A

Scientists' Conceptions of Scientific Inquiry Protocol, 2001

1. What is your definition of scientific inquiry?
2. What are the characteristics of scientific inquiry?
3. Describe the earliest scientific inquiry experience that you had?
4. What kinds of skills are necessary to do good scientific inquiry?
5. In what ways does scientific inquiry require higher order thinking skills?

   (Does doing science require skills such as application, synthesis, analysis, and evaluation?)
6. Can you provide an example of an activity that requires doing scientific inquiry?
7. Is scientific inquiry valuable? Who should do scientific inquiry? At what age?
8. Would you like to add to or make changes to your definition of inquiry?

THE LEARNING CORRIDOR: EXPLORING AN URBAN \MAGNET SCHOOL INITIATIVE

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The American Association for the Advancement of Science (AAAS), and the National Research Council (NRC) of the National Academy of Sciences have each sponsored science education reform initiatives which share the overarching goal of "scientific literacy" for all Americans (AAAS, 1989; NRC, 1996). Although the notion of scientific literacy is the guiding principle underpinning this current wave of reform, the term itself has been around for nearly half a century (DeBoer, 2000). Unfortunately, it is not until very recently that the science education community has, to a significant extent, begun to seriously consider the full implications of cultivating science learning for *all* students. Science literacy directly connotes that, as a science education community, we are not merely interested in nurturing those students who show a propensity for science, and thus focus on fostering the next generation of scientists, but we wish to truly develop a scientifically literate citizenry prepared to fully participate in the democracy of the 21st century.

Most recently, the National Association for Research in Science Teaching has dedicated three entire issues of the *Journal of Research in Science Teaching* [38(8)(9)(10)] to exploring various aspects of urban science education. The editors of this series nicely summarize the state of urban science education as they conclude in the preface of the third edition, "The papers (in the series) offer no panacea but provide considerable food for thought for practitioners, policy makers, and researchers." [p. 1064, 2001 (10)]. Clearly, more questions than answers exist regarding the state of urban science education and significant challenges exist in reaching all children in this reform movement, specifically those in urban environments.

To date, research within the context of urban science education has primarily examined the achievement gap between minority and non-minority students, described various urban reform models, and outlined conceptual frameworks for research in this area (Hammond, 2001; Knapp & Plecki, 2001; Norman, et al., 2001; Swanson, et al., 2000). This study was designed to build upon the literature that outlines and examines specific urban reform models of math/science education. In the pilot phases of this research project, we will begin to evaluate specific components of student achievement in grades K-8 that may lead to clear indicators of student success in a high profile, grade 9-12 math and science academy.

Background

The *Learning Corridor,* an urban renewal project, was first initiated due to a landmark Connecticut Supreme Court decision (Sheff vs O'Neill) in 1996 (Mazzocca, 1996). As stated, the claim filed by the plaintiff, Milo Sheff and sixteen other African American, Latino and white public school children, stated that Hartford metropolitan schools are segregated on the basis of race and economic status. Because Hartford schools lacked adequate resources, these school children are deprived of their constitutional rights to equal educational opportunities and minimal adequate education. After a lengthy court battle, the court found that: (a) poverty, not race or ethnicity, is the main cause of the low educational achievement of Hartford school children; (b) students are provided with a minimally adequate education under the constitution because they receive similar resources, educational program, and curricula as students in other communities, (c) school district lines would have to be redrawn to remedy the racial, ethnic, and socioeconomic isolation in Hartford schools, and (d) a mandatory intervention based on coercion would not ensure educationally desirable results.

Using education as the cornerstone of urban revitalization along with the underlying decision of the Sheff vs O'Neill, Trinity College launched a Neighborhood Revitalization Initiative. In cooperation with the Southside Institutions for Neighborhood Alliance-SINA (area institutions including Hartford Hospital, the Institute of Living, Connecticut's Children's Medical Center and Connecticut Public Television and Radio), the goal of the initiative was to decrease the educational disparity within the urban schools and local neighborhoods.

The *Learning Corridor* is a $110 million campus on a 16 acre block adjacent to Trinity College and several buildings of SINA. This K-12 campus consists of: the Inter-district Montessori Elementary School, Hartford Public Middle Magnet School, a high school resource center that includes the Greater Hartford Academy of Mathematics and Science, the Greater Hartford Academy of the Performing Arts, Professional Development Center, a Family Resource Center, a Community Theatre and a Boys & Girls Club. The educational opportunities provided by the *Learning Corridor* extend beyond the neighborhoods of Hartford into the suburbs of the surrounding metropolitan area. . The key component of this partnership is that for the first time, a major urban neighborhood revitalization project has targeted the education of urban youth as the primary focus of the project's success.

Methodology

Research was initiated in the fall of 2001, and is exploring the Greater Hartford Academy of Mathematics and Science (The Academy) within the context of a qualitative case study. Our preliminary work describes the culture of this setting within the framework of the primary mission of The Academy, an urban based Inter-district Math & Science Magnet School. We anticipate that future work will specifically focus on additional complimentary elements of the daily life at the Academy, the student-based outreach programs and professional development initiatives for teachers.

The guiding research question for the initial phase of this study will be, "What's going on here?" (Wolcott, 1988). Marshall and Rossman (1989) write, "One purpose of qualitative methods is to discover important questions, processes, and relationships, not to test them" (p. 43). To accomplish this, various data collection techniques will be utilized, including: (a) in-depth, open-ended interviews with teachers and students; (b) direct participant observation; and (c) written documents, including such sources as program records and student work (Patton, 1987).

This site has been selected because it represents a state-of-the-art, collaborative urban initiative designed to meet the needs of a racially and socio-economically diverse population. Numerous questions exist with regard to the overall effectiveness of such a program. Additionally, there are questions regarding the "consistency" of such a program designed to target high achievers in science and math and the notion of "science literacy for all" (AAAS, 1989; NRC, 1996). It is anticipated that findings from this multi-year study will directly inform science education reform initiatives - particularly those operating within challenging urban environments.

Results and Discussions

This paper specifically discusses the preliminary results in science teaching and learning conducted by at the Greater Hartford Academy of Math and Science (The Academy), as part of the *Learning Corridor's* high school resource center. The Academy was built based on the model of Michigan's Kalamazoo Area Science Center (KAMSC). It is one of the 71 secondary school members of the National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology (NCSSSMST). The National Consortium's mission is to transform mathematics, science and technology education by creating synergies among schools engaged in educational innovation by shaping national policy, fostering collaboration, and developing, testing, implementing and disseminating exemplary programs. The Academy's mission statement and philosophy, as described in their own literature and follows the overall philosophy of NCSSSMST:

> Combining mathematics and science content with problem solving skills in an integrated curriculum, students learn experientially in laboratories by conducting authentic scientific research with applied mathematics.

The overall aim of this program is to provide students with "significant talent" and interest in mathematics, science and technology, an opportunity to be challenged to their maximum potential. Students explore physics, earth/space science, biology, chemistry, algebra, geometry, trigonometry, probability/statistics and using real world and in-depth educational experiences. Experiences include hands-on research, application of mathematics to science and independent study in various disciplines.

The Academy's Mission

The Academy has adopted a broad mission consisting of three components for enhancing math and science education within this urban region: Outreach Programs, Professional Development, an Inter-district Math & Science Magnet School.

Outreach Programs

The Academy specifically provides outreach programs to a diverse population of students who do not regularly attend the daily academic programs offered. The activities offered in the outreach programs vary in time and duration and are given throughout the academic year and summer. Two such examples are *Frontiers in Science* (offered during the summer) and *Explorations* (offered on Saturday mornings during the school year). *Frontiers in Science* instruct students in fundamental science and math concepts that will enhance their academic success in their home schools or once they enter the Academy as math/science students. The focus of *Explorations in Science* is a more in depth study of a specific scientific topic, e.g. forensics, bioengineering or environmental problems as it relates to current social issues. Experiences in *Exploration in Science* include hands-on research, applications and independent study in these various disciplines. Scientific discovery using real world and in-depth educational experiences are designed to empower students with the knowledge and confidence to extend learning beyond the classroom. In addition to *Frontiers in Science* and *Explorations in Science*, the Academy supports a number of after school activities that instruct neighboring elementary school students in basic concepts in mathematics and science.

Participating school districts are encouraged to use The Academy's facilities for instructions outside the normal school day, e.g. after school and on weekends. Teachers may bring classes or other groups such as science clubs for an afternoon, or a series of afternoons to participate in unique learning activities using equipment and media resources not available in their home schools. Resource materials and other curricular enhancement tools have been developed to assist district schools with their academic programs and are available upon request.

Professional Development

Dedicated to preparing today's students to be the scientists of tomorrow, The Academy and Trinity College have partnered to provide professional development opportunities that help teachers learn and master inquiry-based learning techniques while integrating mathematics and science in the classroom. The goal is to provide teachers with the meaningful techniques on state-of-the-art instrumentation and technology. Ultimately, it is anticipated a wide range of students will benefit from teachers participating in professional development workshops sponsored by The Academy.

During the professional development conference held in November 2001, over 250 teachers of mathematics and science participated together in workshops focusing on the integration of science and mathematics. The workshops were led by a team of master teachers paired with university faculty that taught mini-courses in photonics and optics, cellular biology, laboratory skills such as DNA sequencing, Polymerase Chain Reaction and electrophoresis, the use of graphing calculators and topics in discrete mathematics. The guest speaker that concluded the day's events was the renowned deep sea inventor and explorer, Dr. Robert Ballard.

Teachers from participating school districts also have the opportunity to work with faculty at The Academy during the summer workshops. These workshops vary in subject matter and length. Leadership training is available so teachers can serve as facilitators for science, mathematics and technology in their home schools. A curriculum development center provides teachers with teaching modules and materials based on national standards and curriculum frameworks as well as instructional materials using real life examples from local medical, engineering and research facilities. A laboratory and materials workspace is available where teachers can come for a day, a week or longer to create their own materials for use in their own classrooms.

Inter-district Math & Science Magnet School

Opened in the Fall of 2000, the Academy's magnet school is in its second year of operation and the cornerstone of the facility. The philosophy of the Academy can be summarized as "learning science as scientific discovery is conducted". In order to implement this philosophy, the Academy combines mathematics and science content with problem solving skills in an integrated curriculum. This program provides students with exciting scientific experiences through experiential teaching methods. The use of "state of the art" technology enhances student understanding thus enabling them to make connections between science, mathematics and technology with real world applications. These experiences are designed to motivate students toward higher levels of achievement in the natural sciences. Students learn experientially in laboratories by conducting scientific research with applied mathematics. All course work emphasizes problem solving and creative thinking by utilizing many different resources. This philosophy gives students with an interest in mathematics, science and technology, the opportunity to be challenged to their maximum potential.

There are 13 school districts located in the Greater Hartford metropolitan area (Figure 1) that send students to the Academy.

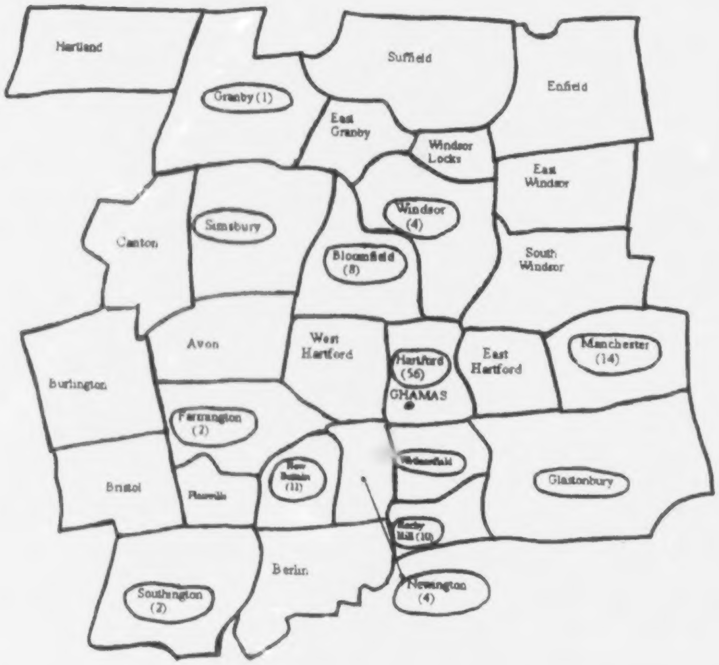
Hartland
Granby (1)
Suffield
Enfield
East Granby
Windsor Locks
East Windsor
Canton
Simsbury
Windsor (4)
Bloomfield (8)
South Windsor
Avon
West Hartford
Hartford (56)
GHAMAS
East Hartford
Manchester (14)
Burlington
Farmington (2)
Wethersfield
New Britain (11)
Glastonbury
Bristol
Plainville
Rocky Hill (10)
Berlin
Newington (4)
Southington (2)

Figure 1. Hartford County. Hartford Connecticut. Greater Hartford Academy of Math & Science (GHAMAS or the Academy) school districts are circled. The number of students participating in the Academy's program are in parentheses.

These school districts include Bloomfield, Glastonbury, Farmington, Granby, Hartford,

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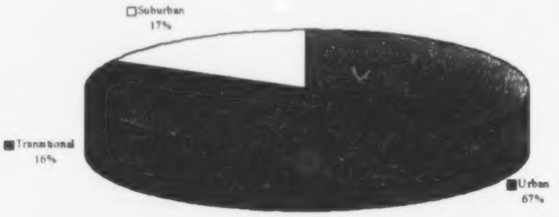
Manchester, New Britain, Newington, Rocky Hill, Simsbury, Southington, Wethersfield, and Windsor. Once a student is accepted and enrolls in The Academy program, they take all their math and sciences classes during their tenure at The Academy. There are 2 sessions during the day offered by the Academy. The morning session caters to freshman and sophomore students who take classes in mathematics (Algebra I, Geometry/Data Analysis, Algebra II & Trigonometry) and science (Earth Science, Physics, Biology with Health in the 21st Century or Chemistry). The afternoon session is limited to junior and senior students. They are required to take Advanced Placement Biology, Advanced Placement Chemistry, and Advanced Placement Physics as well as courses in mathematics (Pre-calculus/statistical analysis and Calculus). In addition, students in their junior and senior years are required to take a minimum of one elective course per year and an independent study under the direction of a faculty member of the Academy or a member of the local college faculty. Students take their other academic classes such as language arts, history and social studies as well as foreign language at their home school during the alternate part of the day, e.g. morning for junior and senior students or afternoon for freshman and sophomore students. Currently there are 165 students that attend The Academy across the two sessions during the day.

The unique atmosphere of The Academy creates an ideal learning environment for student exploration of the sciences. The class size does not exceed 15 students so each student can receive individualized attention from the faculty. Resources are available for each enrolled student includes a laptop computer for all classroom activities and learning outside the classroom and access to state-of-the-art laboratory equipment for work in cell culture labs, laser labs, robotic/electronic labs and molecular genetics labs. Students also have access to nearby Hartford Hospital and Trinity College for additional resources.

Describing the Population

The focus of this paper is on the current graduating classes of 2005 and 2006 (*n*=112). This group was selected because they enrolled as freshman in The Academy's program and will complete their entire high school career in math, science and technology at The Academy. These entering classes, in addition to the class of 2007 and 2008, will be studied from the time they enter The Academy until they graduate. The students who are currently juniors and seniors (*n*=53) began their work at various intervals while The Academy was still under construction so the benefits of the program may not be as clear to understand for these students.

There are 13 school districts that have funded students to participate in the Academy's programs. Two additional school districts have recently agreed to participate in the Academy's program. The school districts were divided into 3 categories as specified by the State of Connecticut categories based on criteria for a need based $11 million grant. These districts are categorized as Priority (urban in this case), Transitional and all "others" (considered suburban in this case). School districts can qualify for this state funding based on several criteria associated with academic deficiencies. The criteria is based on the number of students living in poverty, the number of students that fall below goal of the state's mastery tests (Connecticut Mastery Tests- given in grades 4, 6, and 8 and the Connecticut Academic Proficiency Tests given in 10th grade) and the size of the school district. During any given year, some schools may switch from a priority status to transitional status depending on the change in their demographics. Of the 13 school districts that participate in Academy's programs, 3 are considered priority urban districts (Hartford, New Britain and Bloomfield: 67% of the student population of The Academy); 2 are considered transitional (Manchester and Windsor: 16% of the student population of the Academy) and 5 are considered in the "other" category (Farmington, Simsbury, Southington, Newington, Rocky Hill: 17% of the student population of The Academy) (Figure 2).



Urban: Hartford (Bulkeley, Weaver, Hfd Public), New Britain, Bloomfield

Suburban: Farmington, Simsbury, Southington, Newington, Rocky Hill

Transitional: Manchester, Windsor

Figure 2. Percentage of Students Attending The Academy by School District

The Academy is a magnet school that provides educational opportunities for neighborhood and suburban students alike focusing on a renewal of the neighborhood and community in the center of the city of Hartford. It prides itself on the diverse nature of its student body. Of the 112 students attending the first two years in the Academy, 54 percent are considered minority (Hispanic, Asian American and Black) while 41 percent are Caucasian (five percent did not respond) (Figure 3).

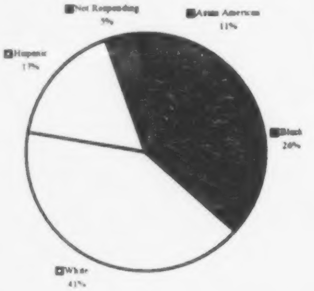


Figure 3. Ethnicity of Students Attending The Academy

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As expected, the priority school districts of Hartford and Bloomfield comprise the largest percent of minority students. Interestingly, of the 112 students, 55 percent are female and 45 percent are male (Figure 4).

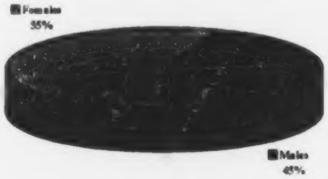

Figure 4. Distribution of Students Attending The Academy by Gender

The students who apply and enter The Academy's program are students interested in mathematics, the sciences and technology. Interested students file a lengthy application that includes transcripts, letters of recommendation from 2 faculty members familiar with their academic work, and a letter of intent describing why they are interested in The Academy. All students who complete an application receive a formal interview with the Director of the Academy as well as members of the faculty. Although the acceptance into the program is a lottery system, the number of students per school district is based on the financial support given by that particular school district. Some school districts only fund students who are in their junior and senior years (the afternoon program) while other school districts fund students in all four years. Transportation to and from the Academy is provided by the individual school district. As expected, the largest proportions of minority students currently attending The Academy are from the urban school districts (Hartford, Bloomfield and New Britain). The transitional school districts (Manchester and Windsor) send primarily white students even though the population of minorities at the school exceeds 35 percent. The suburban school district, as expected, sends

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primarily white and Asian American students. An interesting point is that the urban schools are the only schools where there were no responses to the ethnicity question. (Figure 5).

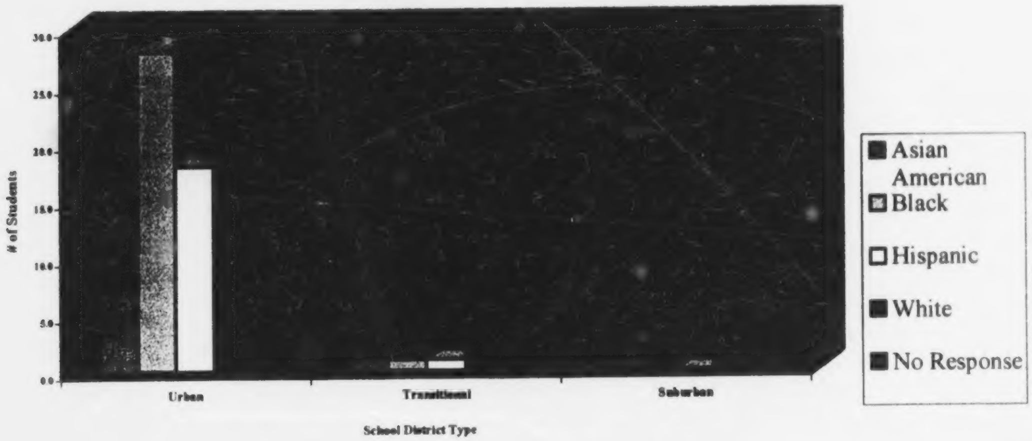

Figure 5 Ethnicity of Students Attending the Academy by School District Category

The goal of the Academy is to increase the number of students attending from the current 165 to the maximum capacity of 300 over the next 5 years.

Students entering the program as freshman are the biggest challenge for the faculty. They have a variety of backgrounds and academic experiences and foundation. Although the GPA of the entering students have little to no variance ranging from a 90 (urban schools) to a 93 (suburban schools) (Figure 6), the background of some students is inadequate in terms of their preparation for the rigorous mathematics and science courses offered at The Academy.

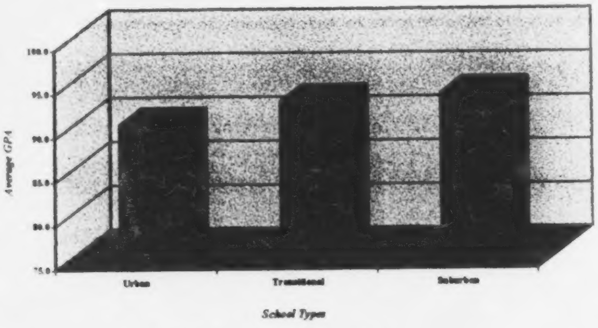

Figure 6. Average GPA of Students Entering The Academy

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To accommodate these weaknesses, a summer program, *Frontiers in Science*, is offered to assist entering students supplemental instruction in Algebra and laboratory skills. This program also introduces entering students to the rigor of The Academy's academic program and makes the transition into the freshman year easier once they enroll in September.

Looking Ahead

Given the preliminary nature of this work, and consistent with a qualitative paradigm, we are certainly left with more questions than "traditional" answers at this point. Further questions to focus on in our future work will include:

1. Is there any way to predict academic success for entering students who enroll in the Academy?
2. Is there a relationship between academic success at the home school and the Academy?
3. What support systems most effectively assist students toward completion of the rigors of the Academy's academic program?
4. Are students who complete the Academy's program academically more advanced when they enter competitive colleges and universities than their peers?
5. Why do students withdraw from the Academy program?
6. Is there a way to balance academics, athletics and the arts with the rigors of the Academy's program?

These questions and others that emerge throughout the process of ongoing work between the University of Connecticut and The Academy will be addressed in future articles.

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SCIENCE EDUCATION IN CALIFORNIA

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Diana Y. Takenaga-Taga, University of Southern California/CSTA
Jan Woerner, California State University, San Bernardino

This presentation focused on the state of science education in California in 2002. Presenters were science educators at California State University (CSU) San Marcos, CSU Fresno, CSU San Bernardino, CSU Long Beach, CSU Dominguez Hills, CSU Hayword, San Diego State University, and the University of Southern California. Presenters discussed such topics as K-12 science teaching in various parts of California, the political climate for science education, collaboratives designed to enhance science teaching and learning, preservice and graduate teacher education programs, professional development programs, special training in science/science methods courses, research in science education, and the California Science Teachers Association. Summaries of the programs are presented below.

Science Education in the Golden State

The Science Instructional Setting in California: Politics, Policies and Potential

California has alternately led the nation and been criticized for its perspectives on science instruction. Science education in the "golden state" centers around science content standards, frameworks, graduation requirements and assessment plans guiding science instruction in instruction in California. These documents, requirements and plans were discussed, along with controversial issues and needs regarding science teaching and curricula.

Research on Teaching

Using the Research on Teacher Wisdom to Identify Learning Outcomes for Science Teacher Credential and Masters Degree Candidates

California State University, San Bernardino shared its developing outcomes assessment model based on the characteristics of the "wise teacher." These characteristics include: a) possesses rich subject matter knowledge; b) uses sound pedagogical judgment; c) has a practical knowledge of context and culture; d) is sensitive to the relativism associated with variations in the values and priorities of both peers and students; and, e) is comfortable with the uncertainty of the outcomes of instructional decisions. The research on teacher wisdom is assisting the science education program in identifying those teacher characteristics that distinguish the novice from the expert. Presenters discussed elements of teacher wisdom and shared with participants how these elements are guiding the program's outcomes assessment in science teacher preparation.

Secondary Science Emergency Permit Teachers' Perspectives on Power Relations in their Environments and the Effects of these Powers on Classroom Practices

Using data collected over a period of five semesters, this study explored how secondary science teachers working on emergency permits view the dynamics of power distribution within their teaching environment, and the effect of these powers on the implementation of inquiry science in their own classrooms. Findings show that teachers need to be aware of power relationship dynamics, and use their knowledge in a constructive way. The "dictator" gave up some of his position power, the "expert" taught her students to become science experts, and the politician showed how political power could be used to enhance students' participation in scientific inquiries.

Teacher Preparation Programs

Integrating Science, Cultural Literacy, and Pedagogy: An Innovative Approach in California's Return to Undergraduate Credential Programs.

General education science courses are being developed to infuse pedagogy, content, and cultural literacy into undergraduate science for students who identify an interest in teaching as a profession. The team of faculty working to develop the course includes science faculty and lab coordinators from San Diego State University (SDSU), faculty and instructors from Mesa College, and science educators in the School of Teacher Education at SDSU. The early focus of the project has been on the general biology course. Changes in this course include inclusion of the California State Content Standards, analyses of science texts and lessons, hands-on and collaborative activities in large lecture sections, and virtual field trips to elementary classes. The biology course was piloted in Spring 2001 at Mesa College and is being piloted in Sprint 2002 at SDSU. Planning is on-going with development of a physical science, earth science, and scientific themes course.

Professional Development Opportunities for Preservice Science Teachers

The Secondary Science credential program at CSU Long Beach requires students to submit a portfolio to exit student teaching. One of the program competencies students must demonstrate is the behavior of a lifelong learner and involvement in professional development. Because of this requirement, students are involved in a variety of activities as preservice teachers. Our belief is that if they become part of a network of professionals early in their careers that they will remain professionally active throughout their careers.

The menu of opportunities for students includes: attending California-STA and NSTA conferences and local science teacher conferences (Orange County in the fall, LA area in the spring); helping judge area science fairs or the state finals of the Science Olympiad (held on our campus each spring); teaching in a summer science camp which has an extensive professional development component (Summer Science at the Beach). They are invited to participate in activities sponsored by the Long Beach Area Science Educator's Network, a partnership of K-16 science educators. Science Education has also been the focus of several meetings of the Future Educators club on campus. Initial findings suggest that once students become professionally involved they continue to find the education, support and activities worthwhile. While some students only attend one conference and join a professional organization (NSTA, AAPT, NABT, etc.) most do much more. We are starting to see very recent graduates taking on leadership roles in their schools, become voices in their district, and active professionally. This will have a multiplier effect when these teachers mentor the next cohort of student teachers.

Inspiring Creative Thinking and Innovativeness in Prospective Elementary Teachers - Project SPARK

Preservice science methods courses have been modified to stimulate creative thinking, and thus creative teaching, by student teachers. Inventor's Workshops, Imagineering, Fantasy Trips, Magical Interludes, Brainwarping, Humor, and Science/Fiction/Art Blending are regularly used to immerse methods students in inventing "off-the-track" science lessons for elementary classes. Research related to the project has investigated the degree to which student teachers pass on the SPARK of creativeness to children in their elementary school classes.

Including the Free Activities Guides of Project WILD and Project Learning Tree within the Methods Courses for Teachers

One CSU course on methods of teaching science for elementary-school teachers includes two workshops, each for six hours. These workshops provide the candidates for the teaching credential with the free "Guide Books" available through Project WILD and Project Learning Tree. Each book contains about one hundred excellent activities that involve the students in hands-on inquiry. They are excellent resources for the teachers, motivate the teachers to do interesting lessons with their students, and relate science activities to other subjects, e.g., language arts, art, mathematics, and the social sciences. Because the activities are especially strong in botany and zoology, the teachers are not fearful of the scientific concepts and begin to view science activities as an excellent way to involve and motivate their students.

Pathways to Professionalism Intern Program: A Two-County Partnership

There is great need for qualified and appropriately credentialed teachers in California. Statistics available from the California Department of Education (CDE) (http://www.edsource.org/) indicates that two-thirds of public school districts employ at least some teachers without appropriate California credentials. Rising student enrollment and class size reduction have been the major factors driving school districts to hire under-qualified teachers. The CSU is a major preparer of teachers. Many of these teachers are in an Intern program. The Multiple and Single Subjects Intern programs at California State University, San Bernardino (CSUSB) are supported by the College of Education at CSUSB and by a California Commission on Teacher Credentialing (CCTC) grant to the Riverside County Office of Education (RCOE) – CSUSB partnership. This is part of the Pathways to Professionalism continuum that supports students in the Pre-Intern, Intern, and BTSA programs. The two-county collaborative is comprised of the RCOE, the Multiple Subject and Single Subject credential programs at California State University, San Bernardino, and the 54 school districts (including

642 schools represented), with whom the two programs have Internship Agreements. The major successes of the program have been the increase in the number of Interns served, the pairing of buddy teachers with Intern teachers, and the training of faculty, Intern supervisors, and buddy teachers. Challenges include the continually increasing number of students served, the interactions between CSUSB and the many partners, and the requirements of the annual reports.

"A Head Start on Science" Project at California State University, Long Beach

In 1995, the Department of Science Education of California State University, Long Beach received a grant from the US Department of Health and Human Services to conduct a project entitled "A Head Start on Science." The purpose of the project was to demonstrate, evaluate, and replicate a training prototype for Head Start teachers, teacher assistants, and home visitors. Almost 500 teachers have attended Long Beach workshops through this national demonstration project. Training products produced include a Teachers Guide, a how-to manual to help others to replicate the training, and a video focusing on engage young children in developmentally appropriate science instruction. With the support of a grant from the American Honda Foundation, the project is now conducting Leadership Institutes for teams of educators interested in establishing "A Head Start on Science" training and dissemination centers.

Programs for Preservice and Practicing Teachers

The Fresno Collaborative for Excellence in the Preparation of Teachers (FCEPT)

The Fresno Collaborative for Excellence in the Preparation of Teachers (FCEPT) is a collaborative partnership between California State University, Fresno, Fresno Unified School District, and Fresno City College in its second year of funding from the NSF. This collaborative involves early field experiences for Single Subject Science and Math Preservice Teachers; university and college science and mathematics course revision activities; special mentoring and support of new science and mathematics teachers; and a range of special academic year and summer programs for all participants. This presentation shared experiences within FCEPT to date.

Programs For Practicing Teachers

California Science Teachers Association: Professional Development

Professional development needs for teachers in California are changing. The California Science Teachers Association has begun looking at new ways to better serve its members by offering a professional development strand at its Annual Conference. This year, CSTA will offer The Nature of Science for college credit at its 2001 A Science Odyssey Conference in Palm Springs, California. Evolution will be the focused topic of the coordinated workshop strand. The conference draws an audience of between 3000 to 4000 science educators through out the state of California.

Inquiry, Cultural literacy, and Informal Science Education Share the Spotlight: Lessons from the Development of a New M.A. degree in Science Education.

This year marks the beginning of a new master's degree option in the School of Teacher Education at SDSU. This program has foci on inquiry science and multicultural science education. The student population includes elementary and secondary teachers, as well as informal educators and local scientists interested in outreach. The depth of knowledge and curiosity in such a varied group adds richness to the program. This program, part of the Curriculum and Instruction option, includes courses in science education research, policies, and practices. One unexpected outcome has been the self-reported improvement in instruction in elementary, secondary, and informal settings due, in part, to the sharing of experiences and education among the students in the M.A. program.

Graduate Opportunities for Teachers in North County San Diego: A Masters in Education Degree Integrating Science, Mathematics and Educational Technology

The College of Education at California State University San Marcos has a new masters degree program in Science, Mathematics and Educational Technology for Diverse Populations. The purposes of this program are to prepare site and district educators for positions of leadership in Science, Mathematics and Educational Technology; to model the integration of the three fields of emphasis; and to advance opportunities for success for diverse learners in those fields. The program has a strong multicultural education focus. Issues, materials, and strategies for effective instruction of multicultural/ multilingual education are emphasized.

Graduate students who are enrolled in the program are currently teaching grades K-12 in area schools. There are several elementary teachers, as well as secondary science teachers, math teachers and technology teachers currently enrolled in this masters' option. Students take 15 units of required core courses (Educational Research, Multicultural Education, and Current Issues and Research in Science Education/Math Education/Educational Technology); 9 units of specialization courses one or all of the 3 areas of emphasis; 6 units of science/math/technology content electives; and a thesis project for 3 units. The total program includes 33 units.

WHEN ARE ANALOGIES THE RIGHT TOOL? A LOOK AT THE STRATEGIC USE OF ANALOGIES IN TEACHING CELLULAR RESPIRATION TO MIDDLE-SCHOOL STUDENTS[1]

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Analogies have been seen as both a means of natural learning and an important teaching method (Gentner, 1989, Hatano and Inagaki, 1988). In a science education context, analogies are comparisons between something familiar to students (the base) and an unfamiliar area in science that teachers want students to understand (the target) (Glynn, 1991). Analogies may serve a number of functions in helping students learn science. Functions that have been hypothesized include: 1) the base serves to help students construct an imperfect preliminary model (M1) which is later modified by students to approximate the scientists' model (Clement and Steinberg, in press); 2) knowledge may be transferred or extended from the familiar base to the unfamiliar target so that students do not have to construct the entire target (Clement, 1993; Gentner,1989; Minstrell, 1982); 3) the base and target are both examples of a larger pattern or class of knowledge and help to illustrate this pattern (Gentner, 1989); 4) analogies may help activate visual imagery (Duit, 1990; Johsua and Dupin, 1987; Yang and Wedman, 1993); 5) analogies may be memorable and thus increase the memorability of new knowledge (Wong, 1993); 6) analogies may provide affective and motivational support for learning (Gowin, 1993 in Duit,1990); and 7) student-generated analogies may serve process goals such as the activation of creativity and imagination and may help students generate as well as evaluate hypotheses (Dagher, 1994; Wong, 1993).

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The *Energy in the Human Body* curriculum uses analogies and other tools to help middle-school students understand cellular respiration (Rea-Ramirez, 1998). Cellular respiration is the biochemical system in nearly all living things in which the chemical energy contained in the glucose molecule is transferred to molecules which serve to store and transport energy so it can be used in the cell's functions. The curriculum is different from other middle-school life science curricula in that it is:

- Research-based, having been developed after a set of individual and small-group tutoring interviews.
- Integrated, in that cellular processes are connected to the body systems that assimilate and transport food, oxygen and the waste products of cellular respiration. The entire curriculum forms a coherent "story" about how energy is used in the body.
- Strategic, in that multiple teaching and learning tools are used to help students build understanding, and in that these tools are employed as deemed appropriate for specific learning goals. Teaching and learning tools used in the curriculum include analogies, cooperative/small-group work, "learning by drawing," dissonance-producing questions, and recall of students' "daily life" experiences. The general pedagogical approach in the curriculum is model generation, evaluation, and modification (GEM) cycles, with the above tools used to assist students in the process of developing and revising mental models (Rea-Ramirez, 1998).

In this paper, we will examine the ways in which analogies are used in the *Energy and the Human Body* curriculum and discuss some preliminary assessments of successes and difficulties. In addition, we will look at what our first year's trials suggest about the effective use of analogies in the middle-school classroom. We will also suggest some characteristics "good" analogies for middle-school students. Lastly, we'll explore the question: When are analogies the "right tool" to use in helping students understand science concepts?

The Use of Analogies in the *Energy in the Human Body* Curriculum

The *Energy in the Human Body* curriculum is used to teach middle-schoolers concepts and knowledge that are largely unfamiliar to them. The curriculum has the ambitious content goals of teaching four body systems, cell structure and function concepts, and energy concepts that are related to human physiology. The subunits are taught in interconnected fashion, and for understanding rather than memorization. The teaching approach is also student-active, in that many if not most of the ideas used in constructing knowledge come from students themselves (Rea-Ramirez, 1998).

The curriculum was developed after a series of tutoring interviews and a "trial run" of the teaching approach with four middle-school students (Rea-Ramirez ,1998). The ideas in this paper are based on observations made during the first year's trial in three middle school classrooms, in which both successes and challenges in the use of analogies were seen. Our observations were used to criticize and revise the curriculum for a second year of testing. In this paper we reflect on patterns in this formative improvement process in order to form hypotheses about purposes and techniques for using analogies in instruction.

Table 1 shows examples of analogies used in the curriculum. The analogies used vary both in complexity and in purpose. Complex analogies such as the school analogy have a number of elements that correspond or "map" between base and target. Simple analogies, such as the "ear of corn" analogy, have only a few elements which map. These two analogies also vary in purpose, with the school analogy being designed to help students understand the functions of cell parts and the relations among them, and the ear of corn analogy being designed simply to generate a visual or geometric model which helps students understand how cells are arranged.

The analogies described in Table 1 are intended to assist students in constructing content pieces that are of critical importance in understanding the "story" of cellular respiration. In our first year of classroom curriculum trial, they were explicitly identified as analogies by the teacher and in the manual used by students. In addition, the manual asked teachers to "map" the analogies, drawing lines from each feature of the base to the corresponding feature of the target. The processing of these analogies took a significant amount of time, from approximately 20 minutes for the ear of corn analogy to an entire class period or more for the school analogy.

In addition to the formal, structured analogies described above, we recognize a second type of way in which analogies are used in our trial classrooms. We have found that both students and teachers use our analogies informally, to illustrate points or explain their ideas to each other. Some students and teachers also engage in the spontaneous use of analogies and metaphors that they have generated themselves, with such use tending to increase as the curriculum progresses. Some examples are as follows. In the small group trial that began this project, one student referred to red blood cells as "like a UPS truck," in that red blood cells drop off oxygen to and pick up carbon dioxide from other cells in the same way that a delivery truck might drop off one package at a house and pick up another. A second student, looking at a model of lung structure, described it as "like a tree." In the first year's classroom trial, a student

Table 1

Examples of analogies used in the "Energy in the Human Body" curriculum

Analogy	Mappable elements	Complexity	Purpose/function
Ear of corn	Arrangement of kernels is like arrangement of cells - both are patterned with little space in between	Simple	Visual/geometric
School analogy	The functions of some school parts are similar to the functions of some cell parts	Complex	Functional
Fire analogy	Fire consumes O_2 and fuel, releases energy CO_2 and water. Mitochondria obtain energy from glucose using O_2, with CO_2 and water as wastes.	Complex	Functional
River delta analogy	A river branches into many smaller branches, blood vessels branch into smaller vessels after leaving the heart	Simple	Visual/geometric
Water pipes analogy	Branching water pipes in a city bring water to houses., blood reaches cells through vessels	Simple	Functional and visual/geometric
Grape analogy	The arrangement of grapes and their stems is similar to the arrangement of alveoli and bronchial tubes in the lungs	Simple	Visual/geometric

described the valves in veins as being like "lobster traps," in that passage or movement occurs in only one direction.

We recognize a distinction between the ways the formal analogies that are structured into the curriculum are presented and the spontaneous way in which analogies and metaphors are used in classroom dialogue. The former are presented in a structured way because of their central role in students' construction of understanding. Our formal analogies are also sufficiently complex as to require careful explication. Informal student and teacher use of metaphors and analogies, on the other hand, generally seems to be for the purpose of illustrating one or a few simple points. Elaborate mapping and explication may not be needed in such cases.

Observations and Reflections on the First Year of Classroom Trials

In the first year's trials of the curriculum, we found that nearly all students were able to map corresponding elements of the base and the target correctly by drawing lines between drawings of the two. We also found that many, although not all, students, exhibited understanding of the purpose of analogies by generating appropriate analogies on their own when asked to. In addition, we noted spontaneous generation of analogies by students during class discussions. Teachers were also observed to invent analogies and to use them as teaching tools.

We also noted some problems with classroom use of analogies. First, we found that students sometimes expressed functional analogies visually. For example, when students drew cells they often drew images of food instead of mitochondria. This confusion may have resulted when students mapped the visual rather than the functional aspects of food onto mitochondria. Second, we found instances in which students "overmapped" analogies, attempting to transfer elements of the base to the target that were inappropriate. We also noted that one of the teachers had trouble helping students understand the process of mapping analogies. These problems led us to believe that students and teachers needed more explicit instruction and support in processing analogies than we had provided.

Analogies are now presented to students and teachers with the following types of instruction and support:

- The teachers' manual includes an introductory section that explains the pedagogical basis for the use of analogies and gives teachers a set of steps to use in introducing analogies. It also discusses potential pitfalls in using analogies in the classroom.
- The teachers' manual has the student manual embedded within it. Boxes surrounding the student manual give teachers tips for presenting the analogies and prompt them to reflect on the pedagogical basis for using analogies.
- Students are asked to draw and map base and target as individuals, rather than in small groups. Students are then asked to discuss the information implicit in their drawings both in small groups and as a class. This requires students to process their understandings thoroughly, and give them a chance to learn from other students.
- Students are given tables in which they enter elements of base and target that do and do not correspond when mapping complex analogies such as the school and fire analogies.
- Teachers and students are guided explicitly as to which elements of the base to examine in order to understand the target. For example, in the ear of corn analogy students are told to look at the pattern or arrangement of the kernels and not at their hardness and colors.
- The students' manual includes "check-ups" or quizzes in which students are asked to reiterate understandings gained through analogies.

- The students' manual also contains opportunities for students to reflect on analogies metacognitively.

Analogies and Middle-School Students

Our experiences suggest that analogies can be used as learning tools by middle-school students. We have found particular success with the school analogy, which is familiar to students and which helps them understand otherwise fairly inaccessible material. Students recall the school analogy easily and use it spontaneously in written work and oral discussions. The school analogy also gives the students access to a functional understanding of the cell and its parts. This makes it less likely that students will learn cell parts in a meaningless "rote" fashion and provides a conceptual foundation for understanding mitochondrial function. We have also seen students correct their models when prompted to remember an analogy. For example, several students who were drawing cells in tissue as widely dispersed rather than close together were asked what they learned from the ear of corn analogy. The students immediately revised their drawings to show cells as contiguous. This suggests that students have retained these analogies and can use them to correct and/or reinforce understandings.

Even these analogies, however, were not understood by all students in trials in which they were not mapped and explained explicitly. In trials in which these analogies appeared to be used successfully, teachers drew connections between features of the base and corresponding features of the targets. In addition, analogies in which the base was not familiar to the students appeared to be used less successfully by students. For example, an analogy in which a party popper was compared to energy-rich ATP molecules seemed to have confused a number of students, who were unable to say what they learned from the analogy. Mapping of this analogy was difficult for both teachers and students, and we failed to include a step in which students became familiar with the elements of the base before developing the analogy.

While we cannot draw specific conclusions from our research to date, we do believe we have evidence to suggest that the careful, elaborate processing we have introduced with our formal analogies in the second year of our trial is needed for understanding. We might therefore suggest that a good analogy for middle-school students is one which is either already familiar to them or one which they become familiar with through careful and guided examination. In addition, we suggest that because correspondences between base and target must be understood, a high proportion of clearly "mappable" elements is a feature that would define a "good" analogy.

When are Analogies the "Right Tool?"

We consider analogies to be useful to students who are learning about the human body because they help students build visualizable mental models that are transitions to our "target" models - models that are like scientists' understandings. As shown in Table 1, we believe many serve to provide the foundation for new visual imagery, and that others provide a basis for a more conceptual functional understanding. We have also observed that students tend to find analogies engaging and approach them actively, suggesting that they may serve motivational and process goal functions. In addition, because analogies must be thought through to be understood at all, we suggest that analogies encourage active student construction even in students who are not accustomed to thinking actively in school science.

We recognize that, if they are to be understood by students, analogies, especially complex ones, require highly-structured and intensive processing. We therefore reserve analogies for concepts that are not accessible to students through demonstrations or experience and that can not be readily constructed by students through discussion and inference. We use analogies to introduce the target concepts in Table 1 - cell arrangement, cell parts, mitochondrial inputs and outputs, blood vessel and lung structure – because they can not easily be built by students themselves. In contrast, through logic and experience, students are rather easily able to construct models in teacher-supported discussion such as the "two tube" model of the throat, in which stomach and lungs are connected to the mouth by separate tubes, without the more directive guidance of analogies. With some prompting by the teacher, students have access to such experiences as choking, burping, and swallowing, which they can use as "clues" when they try to infer their own internal structure. They are also able, with teacher support, to produce ideas such as the inference that if they did not have two tubes, they would be likely to get air in their stomachs and food in their lungs. The target concepts that are taught with analogies are unlike the "two tube" concept in that they are not easily understood by students accessing their own experiences.

The use of analogies is also reserved for important concepts, concepts that are prerequisites to further learning. The ear of corn analogy is a case in point. Preliminary research suggested that some students see body cells as having no particular arrangement, as being loosely packed and not contiguous (Rea-Ramirez, 1998). We deem the understanding that cells are, on the contrary, arranged contiguously, with little intercellular space, to be quite important. Students will, later in the curriculum, be expected to be able to develop understandings of oxygen and carbon dioxide transfer between cells and the blood in capillaries. In order to construct the correct model of the capillary's proximity to the cell, students must have a model in which cells are contiguous. We therefore consider the ear of corn analogy to serve the important content goal of helping students understand how cells are arranged in the body.

Lastly, we have developed criteria that help us evaluate the effectiveness of analogies. As discussed above, one criterion of effectiveness is familiarity and/or accessibility of the base. The ear of corn analogy, for example, is made accessible to students by giving them an actual ear of corn to look at, hold, and draw. The fire analogy to mitochondrial respiration is explored by lighting a candle in a jar, then covering the jar until the flame dies. This demonstrates to students that oxygen is needed for combustion. A second criterion of effectiveness is a high ratio of mappable to non-mappable elements. The fire analogy, for example, maps almost completely to respiration in mitochondria, and the most important exception - the fact that chemical energy released in the cell is captured and used rather than being converted to heat and light - is instructive.

Summary and Conclusions

Analogies are one of a number of tools used in the *Energy and the Human Body* curriculum. In this paper we have we reflected on patterns in our observations of strengths and weaknesses in analogy use in our first round of classroom trials. We have used these reflections to develop hypotheses about appropriate general purposes and techniques for using analogies in instruction. These hypotheses should be subjected to evaluation and improvement in further research. We have come to use analogies in areas of the curriculum which students can not build themselves through logic or experience, such as cell arrangement and mitochondrial inputs and outputs. We believe that the processing students use in examining and understanding the analogies included in the curriculum is active, in that students are asked to examine and reflect on each analogy. We give preference, however, to starting from students' own models when they are available, and use analogies where preliminary research indicates that a concept can not be readily developed by students from their own experiences.

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INFUSING INQUIRY INTO SCIENCE METHODS COURSES: THREE PERSPECTIVES AND STRATEGIES

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Our Goal

This interactive session shows how 3 science educators are trying to infuse inquiry into their methods courses. Science methods courses at the early childhood level, middle grades level and secondary level will be explored. Each presenter will discuss the challenges of preparing pre-service teachers in doing inquiry, and strategies that they have used. Audience members will be encouraged and expected to share their experiences and wisdom.

Science educators have been given a mandate to prepare future teachers in ways of infusing inquiry and authentic investigation into their classrooms. The National Science Teacher Association's "Standards for Science Teacher Preparation" (1998) have two specific areas that address this mandate:

Content

The program prepares candidates to structure and interpret the concepts, ideas and relationships in science that are needed to advance student learning in the area of licensure as defined by state and national standards developed by the science education community.

Content refers to:

- Concepts and principles understood through science.
- Concepts and relationships unifying science domains.
- Processes of investigation in a science discipline.
- Applications of mathematics in science research.

Inquiry

The program prepares candidates to engage students regularly and effectively in science inquiry and facilitate understanding of the role inquiry plays in the development of scientific knowledge. Inquiry refers to:

- Questioning and formulating solvable problems.
- Reflecting on, and constructing, knowledge from data.
- Collaborating and exchanging information while seeking solutions.
- Developing concepts and relationships from empirical experience.

Accredited institutions are asked to provide documentation on how they are meeting these guidelines. Institutions are expected to provide indicators that define these standards for their institution, descriptions of learning experiences that support these standards and assessment data on how their teacher education candidates implement these standards.

Among the "National Science Education Standards" (National Research Council, 1996) are Professional Development Standards which state,

> Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching. Learning experiences for teachers of science must: (a) Address teachers' needs as learners and build on their current knowledge of science content, teaching and learning; and (b) Use inquiry, reflection, interpretation of research, modeling, and guided practice to build understanding and skill in science teaching. (p. 62)

In preservice teacher education, methods courses seem to be the ideal (and often designated) place to concentrate on these standards. Among middle school and secondary programs, approaches are varied, as are the structure of programs within which methods courses are nested. For instance, some programs include a sequence of methods courses, while others may only include one. Regardless of this varying structure, it is clear that methods courses bear the burden of assisting preservice teachers to move into teaching in ways that many of them have only minimally experienced, from the role of student.

Recent research and modification of preservice teacher education programs in science education has included applying conceptual change constructs (Stofflett, 1994), as well as emancipatory teaching (Koballa & French, 1995) in preservice coursework. Both of these approaches build on constructivist ideals, which include moving from teacher-directed to student-centered instruction, in order to model effective teaching and encourage a wider range of interactions among participants in the course. So what does this look like in the methods course?

The Challenge

All science educators use the language of inquiry in our teaching and our research. The challenge is to "walk the talk" or, in other words, teach in the ways that we want our teacher candidates to teach. That is, model inquiry teaching and help them transform their understandings and experiences for their students. In these days of increased accountability we need to be able to document how are candidates have learned these skills, and how they are using them in field experiences and during induction years of teaching. This session starts that conversation and will build a learning community to explore the options and possibilities.

Early Childhood/ Lower Elementary Education: Facilitating the Shift from Technique to Perspective

The challenge of preparing early childhood/elementary education candidates is their lack of content knowledge combined with their inexperience in using the "big ideas" of science curriculum. As a result, many candidates enter the science methods course viewing science teaching as a matter of grasping and applying science teaching "techniques" to a series of more-or-less unrelated science topics. This science methods instructor will first show how to engage candidates in basic but meaningful investigations that candidates can easily use in the field. The instructor will then discuss how to engage candidates in several levels of on-going dialogue that aim to facilitate a change in perspective from a narrow focus on the techniques of teaching science towards a broader focus on issues of science inquiry.

Facing the Problem of Content Knowledge

The majority of early childhood pre-service teachers we teach are initially fearful of teaching science. This fear is particularly problematic as they are working towards a Grade K-8 Ohio teaching certificate. Hence, the students recognize that although they really want to teach Kindergarten, the reality is that their first teaching position is more likely to be in 4th or 6th grades (grade levels where the bulk of Ohio Proficiency Tests are administered)). At the beginning of each semester, we ask each early childhood methods class for shows of hands regarding the following two questions: 1) Do you feel you understand the science behind the topics you probably will need to teach your students? 2) Are you confident that you can teach students the "big ideas" of science effectively?

In nine semesters we have never had more than two or three hands out of 20 to 25 students in the class go up in response to either question. When students see their apparent lack of confidence in their science knowledge, they brace themselves for a judgmental reaction from us that they are sure will follow. Instead of judging, we use this opportunity as a point of entry for having students explore their personal histories as learners of science to discover why this is so. In doing this, we guide them in searching for reasons why they feel uncomfortable with their science content knowledge. Ultimately, our aim is to help them to understand the images of science teaching and learning that they bring to their science methods experience.

Prior Images of Science Teaching and Learning

From their first class session, and long before they enter the field component of the course, we require them to write a reflective journal entry following each class session. These early journaling assignments place the students in the role of historical tour guide but they also facilitate students in exploring their individual histories as science learners. We give one of the following writing prompts sequentially as homework following each class session.

1) *Describe your favorite teacher.* Take me on a one-day field trip back in time. As specifically as possible, describe the kinds of things I would see, hear, smell, taste, touch and do if I went back and spent a day with your favorite teacher.

2) *Describe your least favorite teacher.* Again, take me on a one-day field trip back in time. As specifically as possible, describe the kinds of things I would see, hear, smell, taste, touch and do if I went back and spent a day with your favorite teacher.

3) *Informal science learning.* Take me back to a time and place outside of school where, as a child, you learned about science. Where am I? What am I sensing and doing? What would I have learned if I were you?

4) *Formal Science Learning.* Describe a moment of science learning. Take me back to a specific science lesson or activity where you thought you really learned a lot of science. Describe in detail what was happening during that lesson.

5) *Compare and Contrast Teaching Styles.* What seem to be the differences between your favorite and least favorite teachers? Try to find as many similarities as you can.

6) *Compare and Contrast Learning Environments.* What similarities are there between your favorite school science lesson and your favorite informal science experience. Find as many differences as you can?

During class sessions, we build in time to have students work in small groups to share their journal entries. We encourage students to share as much about their entry as they feel comfortable and we encourage them to "actively" listen to each other. We review active listening strategies with them prior to engaging them in the first journal sharing activity and we require them to use this strategy during the activity for two reasons. First, we believe that this activity provides an authentic context within which to practice this communication strategy. Second, it sets a tone of mutual respect and non-judgment in the groups. Following each small group encounter, we have the groups debrief by reporting to the class the trends in their stories.

In our experience using this set of activities, we have found that students inevitably begin to take ownership of several important discoveries. Among these, are: (a) that science was often presented to them as a "pack-of-facts" as their teachers often used textbook-driven approaches for teaching science, (b) that in their worst science courses they seldom, if ever, were allowed to investigate their own questions, generate and then argue a point using their own data, or do anything except textbook-approved activities, (c) that we learn best when we are having fun (attitude and achievement are reflexive), and (d) that play is often as important as more formally structured science activities. In general, these activities lay the foundation for beginning to think about inquiry in ways that are more consistent with the National Science Standards (NRC, 1996) and the ways scientists think about inquiry (e.g., AAAS, 1989).

Minimal authentic experiences

Methods students will often tell an instructor what they think the instructor wants to hear. For this reason, we do not confront the issue of what science is directly, because that discussion will very likely only generate a list of features that students think we want to hear. Instead, we try to lead by example and take opportunities to show students what doing science really could look like. we believe that taking these opportunities is vital because students typically have had few, if any, authentic experiences that lead to inquiry.

The first opportunity comes within the first two sessions of the early childhood methods course when we do "Burning Steel Wool" (see, Krajcik, Czerniak, & Berger, 1999, p. 29-31). This activity involves students working in pairs to make an aluminum foil tray that will hold a sample of one-half of a steel wool pad that has been unwound and fluffed. Students find the mass of the steel wool and the tray using a balance. Once they have recorded the initial mass reading in their journal they light the steel wool sample with a match and let it burn in the tray. Burning is done on the flat desktop with all paper materials and scales moved off the table. After the sample has cooled, the pair again places the tray on a balance and finds the mass of the sample and tray. Then, students find the change in mass of the sample by subtracting the initial mass from the final mass recording. This gives the change in mass of the sample.

When each pair has calculated their mass change, they display their data on the chalkboard so that a class set of data is generated. Students soon discover that, in their words, "it didn't work." By this they mean that there is no apparent trend in the data. Some groups have positive mass calculations, meaning that the mass of the sample increased upon burning. Others have negative mass calculations, meaning the sample decreased in mass upon burning. Usually, one or two groups get no change in mass at all.

Seeing these results, students search the instructor's expression for a reaction. When we tell them that we are very pleased with these results, they slump in their chairs in disbelief.

"But these results don't tell us anything," one student will say.

"I know." I will say. "You need to figure how you can get this activity to tell you something."

With that point of entry, we guide themto look over what they did and identify hidden variables and flaws in their method for doing the activity.

After much discussion and debate the sudents eventually reason that one hidden variable is that some groups used "elementary style" baances, while others used "two pan" balances, and still others used "triple beam" balances. We then help the class to develop a new protocol for the activity that features these changes in methods After we have worked these methods out as a class we repeat the "experiment" using their pntocol to see if we can get reproducible results.

Upon redoing the experiment, studentssee that the mass of the steel wool increases when it is burned. This result only serves to touch of more debate about whether this is the correct result or not. At this point, we begin to scaffold students. We ask them to fold a blank sheet of paper in half horizontally. On the top half of the paper we ask them to draw a picture of what they think the steel wool would look like befor it burns when viewed with a "real powerful microscope." On the bottom half, we ask themto draw a picture of what it looks like after it burns; again, as they think it would look whenviewed from a real powerful microscope. After they have drawn the pictures by themselves (ahomework assignment), we encourage them to get in groups of three or four and discuss their drawings with each other. Then, we ask them to work on a drawing that all members of their group can more-or-less agree will serve as the "model" for what they think is happening when the steelwool burns.

This activity accomplishes several important goals. First, it helps students to unpack their own ideas about what it means for something to burn. Second, it engages them at an adult-appropriate level in an authentic inquiry that remains relatively non-complex. Third, it enables me to model inquiry teaching for them, And, last, but not least, it provides an opportunity for the instructor to confront with them the fear of, "What do I do when the experiment doesn't 'work' for me." This is the perhaps the most authentic aspect of this activity, because they can visualize themselves teaching a hands-on lesson that "doesn't work."

Minimal pedagogical experience

The steel wool activity provides the first instance where we can explore an authentic problem of science and science teaching with the class. In subsequent class sessions we attempt to create authentic problem spaces for student inquiry. Usually, we investigate problems of understanding the phases of the moon, floating and sinking, and electricity. At various points throughout these lessons we continually signal to students that we need to have two levels of conversation as a class. At the first level, the interactions between the student and instructor are as between students and teacher. At the second level, we invite students to shift roles to become our colleagues and formatively assess my teaching practices and thereby identify principles of teaching and learning science. Our aim for these two levels of conversation is to have them function complimentarily, so that the methods student is doubly situated with respect to problem spaces in science and in science teaching. Here is an example.

Our exploration of phases of the moon begins by watching "A Private Universe" (Harvard-Smithsonian Center for Astrophysics, 1987). After watching the video as a class, we debrief with my students asking them to identify key points that the video attempts to make. Usually, students focus on several key ideas these include:

1) Even well educated people have trouble with this science concept.

2) The high school students did not seem to understand even after the teacher explained all the information.

3) The teacher was not aware of how the students were thinking about the moon's motion.

4) The students need to use the models of the moon, sun and earth themselves.

5) The teacher changed how she taught after she saw her students' interviews.

Following the debriefing, students work within groups to help each other understand the motion of the moon. This involves working in small groups of 3-4 students per group. Each group is given one set of sun, moon and earth models. Each individual is given a packet of written materials that are designed to provide a resource for informing their understanding. We prompt their efforts by telling them that we will be coming around to each group and we will ask them to show how day and night occur, how the four seasons occur, and how the moon phases occur. After about 15-20 minutes, we begin to assess what the students understand by switching into "interviewer mode" and questioning students on a group by group basis.

Interviewer mode involves several changes in my behavior. First, we ask "tell me" and "show me" questions. For example, "Show me how day and night occur." Second, we ask follow-up questions that probe their understanding. For example, "How do you know that the earth spins counterclockwise (when viewed from above the north pole) and not clockwise?" Third, we try to give no indication of which answers are correct and which aren't. Fourth, we practice active listening by repeating back what we have heard the students say and often we follow up with another probing question.

In almost every group the students eventually reach a point where they don't know the answer to my probe. When this point is reached in each group, we intentionally vary the way we respond. In some groups we tell them the answer right away. In other groups we attempt to scaffold their understanding. Occasionally, we end the interaction without telling or scaffolding.

When we have finished interviewing each group, we signal the jump to the second level of conversation by asking, "What did you notice about my behaviors during this activity?" Students give a variety of responses to this question, but eventually they bring up the issue of what we did when they didn't know the answers. As students from various groups talk about this issue, the class soon realizes that we have treated many of the groups differently. At that point, we ask the students to think about the consequences of the decision we made in their group and how we could have handled the situation differently. Inevitably, students begin to offer us contradictory courses of action. We then ask them if they can tell us with certainty when and under exactly under which conditions we should tell them an answer. As they struggle with this, we ask them to consider if the question is best resolved by appealing to rules, to guidelines, or to our own judgment. When many of the students begin to realize the answer is more a matter of judgment than applying rules or guidelines, some students react with unease and in one recent noteworthy case, frustration.

"When are you just going to tell me what we need to know to teach science?" When the instructor probed this statement, he found that, in essence, she wanted him to fashion for her a set of "tools" in the form of teaching "techniques" that would work reliably. She didn't want to hear that she would have to make her own tools and that reliance on techniques alone would not solve the dilemmas of classroom inquiry.

Prior Images of Science

As our work with science investigations progresses, we continue to facilitate students in constructing what is often, for them, a different view of science, even though some of my students to one degree or another resist changing their views towards inquiry-based teaching. Towards the end of the semester as students begin to develop their own lesson plans my work becomes even more clinical in that we use class time and office hour time to meet individually with students. As we discuss their emerging plans, we continually attempt to refocus their thoughts on exactly what it will take to teach science by asking questions within the context of their plans that attempt to get at the following general questions: Is it enough to do hands-on activities? Is it enough that the teacher asks certain questions? Is it enough that the students talk with each other and with the teacher? Through the individualized discussions and mentoring we attempt focus them on the idea that inquiry is not equivalent to hands-on instruction, argumentation, or "bee-hive style" activity done in isolation. Rather, we attempt to help my methods students develop the idea that classroom-based science inquiry is a communal enterprise that requires a moment-by-moment balancing of all three.

Inquiry in Middle Grades/ Upper Elementary Education

The challenge at this grade level can also be lack of content knowledge. Also in these grade levels state testing has usually begun and teachers feel pressured to "teach to the test" and may not feel they have the time to do inquiry. Using Wisconsin Fast Plants and butterfly larvae as the example, this methods instructor will demonstrate how to build candidate content knowledge and model how inquiry can be used to teach content. Inquiry can be infused and become a key element of multidisciplinary units.

“For students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry-based methods (NRC, 1996, p.87). This is the challenge of the elementary science methods courses today. Our students need to be "well-versed" in science inquiry. This means that they understand, experience, and be able to implement inquiry into their science classes.

Inquiry also needs to be taught with some type of science content; it cannot be developed in isolation. (*Inquiry and the National Science Education Standards: A Guide for teaching and Learning*, p.36) The Content Standard for Science as Inquiry: Grades 5-8 is listed as the following:

1. Identifies questions that can be answered through scientific investigations
2. Design and conduct a scientific investigation.
3. Use appropriate tools and techniques to gather, analyze, and interpret data.
4. Develop descriptions, explanations, predictions, and models using evidence.
5. Think critically and logically to make relationships between evidence and explanations.
6. Recognize and analyze alternative explanations and predictions.
7. Communicate scientific procedures and explanations.
8. Use mathematics in all aspects of scientific inquiry.

   Inquiry and the National Science Education Standards: A Guide for teaching and Learning, p.19)

The following project was used in a science methods course at The University of Toledo for two semesters. It describes one way of meeting this challenge.

The Project

At the 1999 NSTA Convention, Dr. Coe Williams from the University of Wisconsin solicited help from various teachers to pilot a protocol that was being developed to integrate Wisconsin FastPlants (Brassica rapa) and the Pieris rapae butterfly. This methods instructor (Janet Struble) was intrigued on how the project illustrated the interdependence of plants and animals. The instructor had worked with FastPlants with seventh graders as a junior high science teacher. The students experienced inquiry through CUE-TSIPS, a NASA project developed for STS-87 mission in the fall of 1997. CUE-TSIPS was quite successful in the learning of life science content and scientific inquiry for junior high students. The instructor decided that this would be a great way to teach inquiry and some principles of life science to science methods students.

In the fall of 1999, the elementary science methods students piloted the first protocol. Feedback was sent to Dr. Williams and revisions were made. In the spring semester of 2002, another group of students piloted the revised protocol. Feedback was sent in and no further revisions have been made. You can assess the original and revised protocols at the following website: http://www:fastplants.org

Elementary Science Method Students

Most of the students have not experienced true inquiry. From their journal writings and class discussions, the instructor learned that most students have done the typical lab experiments that validate what you already know; have seen "cool" teacher demonstrations, and have sat through numerous "boring" lectures on a variety of science topics. Only one student out of fifty-six had any experience with Wisconsin FastPlants.

The students needed to experience science inquiry so that they can know what it is and what it is not. Drawing from this experience, they can get some sense of how to transfer this into the classroom during their field experiences. When the students become teachers, use inquiry to teach elementary science.

Life science is more likely to be taught than the other sciences. Students feel comfortable in dealing with plants and animals. The content is familiar to them. The new experiences designed in the methods class would build upon their prior experiences. The method "inquiry" would be taking them out of the "comfort zone." This was the focus of this project.

The Method

In the elementary science methods classes at The University of Toledo, students use the 5 E Instructional Model as the framework for their lesson planning. The 5 E Instructional Model (BSCS) is an expanded version of the learning cycle developed by Bybee and Landes (1988).

Here is a brief description of the 5 E Learning Cycle:

Engagement exposes students' background knowledge, feelings and skills which impact how they view what is being learned.

Exploration provides students with a common experience with the skills and concepts that target the instructional objective. Students actively participate and explore the topic being studied.

Explanation is done by the students with the teacher acting as a facilitator. Students describe their understanding of what took place in the Exploration phase. The teacher's role is to build upon the experiences of students and help them construct their conceptual understanding.

Extension is designed to allow the transfer and apply this new knowledge in situations.

Evaluation can take place during the other phases. Teacher assesses the progress that the students have made toward the objective. Students should reflect on their learning and be able to do self-assessments.

The students are encourage to integrate technology and other disciples into science. The methods instructor modeled how to integrate technology in the fall. The instructor found that students were proficient in the use of digital cameras and doing PowerPoint presentations. In the spring, this became part of the project.

The experience with the plants and the butterfly is extended to the idea of project-based learning. In project-based science, students investigate real-world questions (called driving questions) that are meaningful to them. A driving question is a well-designed question that is elaborated, explored, and answered by students. It becomes the central organizing feature of project-based science and sets the stage for all activities and investigations. (Krajcik, Czernaik, & Berger, p.66) A driving question of this project could be "How plants and animals depend on each other?"

The Plan

Goal : The student will develop an understanding of what is inquiry and how to incorporate it into the learning of science content.

Objective: The student will

-conduct a scientific investigation FastPlants and its butterfly using appropriate tools and techniques to gather, analyze, and interpret data.

-use mathematics to analyze some of the data.

-develop descriptions, explanations, predictions, and models using evidence gathered from the plants and butterfly.

-think critically and logically to make relationships between evidence and explanations.

-recognize and analyze alternative explanations and predictions.

-communicate scientific procedures and explanations both in oral and written form.

For Spring 2000 the students used technology (digital camera and Microsoft PowerPoint) to illustrate the growth of a plant and butterfly.

"Big Ideas" (Science Content): basic needs of living things, life cycle of a plant, life cycle of a butterfly, interdependence of organisms, camouflage.

Engagement: The students did KWL (What do I **K**now, What do I **W**ant to learn, What I **L**earned) charts (Ogle, 1986) on plants and butterflies. The students worked in groups to compile a chart for the group. These charts were displayed in the classroom. I included the information from this charts in my planning and in our class discussions.

Exploration: This phase used different protocols for each semester . Common to both protocols was the growing of FastPlants and the Pieris rapae butterflies. The students recorded measurements and drew sketches of both plants and butterflies. For the plant, student data included day of planting, day of sprouting, day of the first flower bud, and height measurements. For the butterfly, student data included day of the arrival of eggs, day of chrysalis formation, day of butterfly emergence and length measurements of the caterpillar and chrysalis. The details of each protocol can be found at http://www:fastplants.org.

Explanation: Classroom discussions revolved on what was happening to the FastPlant or the Pieris rapae butterfly. Students provided explanations of life science concepts and constructed their understanding of the concepts. The teacher facilitated this learning by providing resource materials. Data analysis was done such as mean, median, and mode of measurements.

Students also problem-solved on why some organisms perished. How to deal with "Life and death" and "Cycle of Life" in the classroom were discussed.

Extension: This was the springboard on how to do project-based learning. After a discussion on project-based learning, each group develop a driving question for a project.

For an assignment, each student critiqued the protocol itself. "Did the guide provide the teacher with enough information to teach the science contents?" "Were the directions clear? " "Was it doable in a classroom?" The student also provided recommendations for improvement. These comments were compiled and forwarded to Dr. Coe Williams.

Evaluation: The students were informally assessed throughout the whole project. Decisions were based on what was happening in the classroom and information obtained from the students' journals.

The student's critique of the protocol was part of the evaluation. The other part was that the student had to describe a situation in which this protocol or part of it could be used.

Further Discussions

After the experience of the project, discussions revolved around the pedagogical content knowledge of science or the "teacher side" of the project. The instructor shared "the why" behind some of my actions and provided the research that supported the decisions. The students knew what the terms, "constructivism," "learning cycle," "authenticity," etc., meant because they experienced it.

The instructor shared the student samples of the CUE-TSIPS project. Students we informed of other projects that could be done and how to find out about them.

Lessons Learned from Doing the Protocols

Students learned that science class needs to be well-planned. The teacher always needs to have a back up plan. For example, in the first protocol, the caterpillars are removed from the FastPlants when they are about a centimeter in length and placed in the Brassica barn. This is done so that the remaining plants could flower for the butterfly stage. The caterpillars are very hard to find. In one weekend, a few remaining caterpillars ate all the plants. The students had to plant again so that there could be flowers for the butterfly to feed upon and leaves to lay their eggs. This also meant a new set of measurements needed to be done. In the second protocol, a leafy mixture was developed for the caterpillars. The mixture contained radishes, turnips, and FastPlants. Another set of FastPlants were just grown for the butterflies.

There following are just some of the suggestions for change/improvements on FastPlant project:

1. Make the reservoirs larger. The water reservoirs for the plants seem to be too small for long weekends and holidays.
2. Offer simpler and clearer illustrations on steps. The ones given in the Fast Plants workbook are sometimes vague and confusing.
3. Have an oversized calendar/outline in the classroom to show upcoming events/procedures and past procedures/data.
4. Provide a list of books/videos about plants, animals, life cycles, and pollination.

What was Learned about Pre-Service Teachers

Most of the students agreed that this was a "fascinating" project and was intriguing enough to hold student interest. Many stated that they would like to use the project in their classrooms in the future. The majority of the students saw the value of journaling and making daily observations (includes sketches and measurements).

Science methods students experienced the need for "ownership." The students realized that their feedback would be of some valued to another scientist/educator. They also saw how the project could give elementary students this same sense of "ownership." The elementary students could learn how to care for a living thing and how to provide for it. The students would observe the life cycles of living things. They would experience the joy of birth and the sadness of dying, and come to realize that life is passed on to further generations.

The methods students described where the project would be appropriate to use. Many students thought it was more appropriate for grades 3 and up. In the lower grades, it could be done as a class project led by the teacher. In general, the topics that were listed were relation to other plants and animals, migration of butterflies, controlling of pests (the caterpillar is a pest for cabbage plants), and nutrition.

Some students made comments like provide more worksheets for the classroom, data tables to record observations, and a Fast Plants notebook and /or textbook. This told us that they were not able to take a step beyond their "comfort-zone." Their "comfort-zone" is still a textbook and filling in worksheets just as they did in science class. Some students wanted instructions on how to integrate into other disciplines. Even though the class was creative to provide numerous examples of integration, these students still wanted a company (outside source) to tell them what to do.

Four students actually did the growing of the FastPlants in their field experience. These students used the STC kit, "Experiments with Plants" and supplemented the kit with the butterflies. One primary methods student implemented the unit in kindergarten. In the spring semester, 56% of the students taught about plants and animals.

This project was successful in providing science inquiry to methods students. This project was also very labor intensive for both the student and the teacher. It also showed that you do not need a textbook to teach science.

Inquiry in Secondary Science Education: Juggling Multiple Roles and Goals

The challenge at this grade level is not content. Most candidates prepared for secondary science education have a strong content background. The challenge at this grade level is helping them think about how to get their students involved in inquiry. Many of these candidates have done inquiry activities in their Arts and Science coursework, but they have not thought about how to translate these types of activities for middle school and high school settings. Secondary science educators also will often have the impression that advanced students are capable of inquiry, but that general students or "lower level" students need science taught in more straightforward ways. This methods instructor will provide examples of field assignments and tasks given to teacher education candidates to help them infuse inquiry into their classrooms, and make science inquiry a part of the science experience for *all* students.

To explore the role of inquiry in secondary science education three areas will be addressed:

1) Content: A bonus and a barrier and Images of Science

2) Inquiry Experiences and Images of Teaching Science

3) Field Experiences and other models

For each section a brief description of the current status, advantages and barriers will be shared and an example of one or two assignments designed to challenge student thinking.

Content: A Bonus and a Barrier

The challenge at this grade level in general is not content knowledge, unlike what is typical for elementary and middle grades teacher candidates. Most candidates prepared for secondary science education have a strong content background. Most secondary science teacher candidates have the equivalent of a major or minor in a science field. This does not always translate into strong understanding of content. Depending on the coursework they have chosen and how they engaged in the coursework they may or may not have deep understanding of their field.

Secondary science teacher education candidates usually have a wide repertoire of definitions and formulas at their disposal. When pushed to move beyond the accepted definitions and really try to explain a concept or phenomena. They often fall back on the old trick of saying things louder and slower. Another challenge they face is that often science content came easy to them in high school and college and they believe that everyone could also understand things if they just worked harder at it.

Sample Activity – Playing in Science

The first class period (or very early in the semester) a collection of toys are presented to the class. Students are asked to work with a partner or work individually and describe how the toy works and what science concepts the toy represents.

Typical toys provided:

Rattle back or celt
Yo-yo
Spinning top
Newton's cradle
Hand boiler
Rubber ball
Squeeze rocket
Xylophone or chimes
Flipping toy
Jacob's ladder
Magnetic toys
Boomerang
Motion detectors
Balloon powered cars/boats
Happy/sad balls
Density and buoyancy toys

Students must describe how these toys work and represent their explanations on newsprint. They are not allowed to merely use definitions or laws such as Newton's third law. They must use common language and describe and explain how the toy works.

In the follow-up discussion students quickly realize that they can often propose a definition or law that explains the phenomena but when pushed to really explain it their content knowledge may not be as strong as they assumed. Follow-up task later in the semester is to design an inquiry lab that has K-12 students making a toy or describing how a toy is similar and different from the real life object it represents. This is followed up later in the semester with similar activities around topics such as: Seasons, phases of the moon, refraction, water cycle, decomposition, etc..

Inquiry Experiences and Images of Teaching Science

The challenge of infusing inquiry into secondary science courses at this grade level is helping them think about how to get their students involved in inquiry. Many of these candidates have done inquiry activities in their Arts and Science coursework but they have not thought about how to translate these types of activities for middle school and high school settings. One of the dilemmas posed by prior experiences in lab is that often high school laboratory, and university undergraduate laboratory experiences are confirmation labs, or cookbook style labs. Where true inquiry is not a goal of the activity, rather the goal of the activity is to confirm earlier studies. Changing this image of inquiry so that it more geared toward exploring student generated questions and work toward solving real world problems where are there are multiple ways of approaching the problem can be one of the greatest challenges of a secondary science methods class.

A second major challenge is that secondary science educators often have the impression that advanced students are capable of inquiry, but that general students or "lower level" students need science taught in more straightforward ways. In a typical science class where there is a range of student abilities they tend to view inquiry as a luxury to be added to the curriculum if they have time and resources, but not a critical part of science instruction.

The following examples of assignments and tasks are given to teacher education candidates to help them infuse inquiry into their classrooms, and make science inquiry a part of the science experience for *all* students. The goals of the activities described are to model and incorporate The National Research Council (2000) calls the "Essential Features of Classroom Inquiry and Their Variations" -- Page 29

Table 1

1. Essential Feature	Variations			
2. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source.	Learner engages in question provided by teacher, materials, or other source
3. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
4. Learner formulate **explanations** from evidence	Learner formulates explanations after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
5. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
6. Learner commun	Learner forms reasonable and	Learner couched in development of	Learner provided broad	Learner given steps and procedures for

icates and justifies explanations	logical argument to communicate explanations	communication	guidelines to use, sharpen communication	communication.
More -------------- Amount of Learner Self-Direction --------------- Less				
Less --------- Amount of Directions from Teacher or Material --------- More				

1. Technology Assignment Each group (specified by content area, i.e. life science, earth science, physical science) will have 3 weeks to explore the uses of the *Vernier LabPro,* probes, graphing calculator, additional equipment and resources and develop 5 lessons or a 5-day unit that uses the available equipment. Develop a set of lessons that set the context for students to be able to explore their own questions that can be investigated with the technology. The focus for this assignment is to have students explore problems that would be difficult to do with out the technology. The write up for these lessons will be due one week after completion of inquiry time.

2. MicroTeaching– Developing an Inquiry Lesson For this activity you must design a rich context that has several possible questions that students can pursue. Your task is to set the stage for student generated questions, where they will be asked to design a study to explore a question.

3. Classroom based research – Design and conduct a student interview (3-5 students) around the topic for your 10 day unit. Using the provided handout as a guide write up a brief analysis of your interview. Use this as the basis for planning your unit.

4. Developing a Teaching Philosophy Statement A teaching philosophy statement can take on a variety of looks or formats. The following five questions are almost always addressed in a teaching philosophy statement. The answers to these questions are usually a paragraph or two long.

- ✓ Why do I want to be a (insert discipline (i.e. biology, English, mathematics) teacher?
- ✓ How do I believe students learn?
- ✓ Why is my discipline important? How does it improve quality of life?
- ✓ How do my strengths and interests link the first three statements?
- ✓ How do I hope my students will describe me as a teacher?

As an end of course assignment this document has been a strong indicator for me on how my student view the role of inquiry in science teaching and learning.

6. Categorizing Lessons

To have teachers examine lesson plans they have written, found or adapted they are asked to use the "Q-M-S Strategy" described by Hassard (2000). Looking through the activity teachers code the lesson with the following code scheme.

Q question given	**"Q"** question not given
M means given	**"M"** means not given
S strategy given	**"S"** strategy not given

Unit plans that cover 10 days must include at least three different "Q-M-S" strategies.

Field Experiences and other Models -- Dreams and Reality

One of the greatest frustrations of trying to infuse inquiry into methods courses and helping pre-service teachers fully adopt this as a teaching style is the lack of support once they leave the university setting. Pre-service teachers will often leave a program being able to talk the talk of inquiry teaching and the benefits of it. They can even walk the talk in limited ways in controlled settings. When confronted with barriers in schools settings the commitment to inquiry teaching fades.

Concerns about content coverage, preparation for state tests, the need for flexibility in planning and scheduling often prompt cooperating teachers and peers during their first years of teaching to discourage teaching in this manner. Without encouragement and support beginning teachers often revert to very traditional styles of teaching that are text based and laboratory activities that are predictable and easily managed.

Challenges and Questions

1. What types of activities have you used in methods courses to encourage inquiry teaching and learning practices?
2. How do you address the concerns in the field?
3. What is the role of assessment in inquiry teaching?

Conclusion

All science educators will use the language of inquiry in our teaching and our research. The challenge is to "walk the talk" or, in other words, teach in the ways that we want our teacher candidates to teach. That is, model inquiry teaching and help them transform prospective teachers' understandings and experiences for their students. In these days of increased accountability we need to be able to document how our candidates have learned these skills, and how they are using them in field experiences and during induction years of teaching. This session starts that conversation and will build a learning community to explore the options and possibilities.

KEEPING THE INQUIRY IN CURRICULUM DESIGNED TO HELP STUDENTS' CONCEPTUAL UNDERSTANDING OF CELLULAR RESPIRATION

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The National Research Council (NRC) (1996, 2000) endorses science curricula that actively engage students in science using an inquiry-based approach. This approach has shifted the focus of science education from the traditional memorization of facts and concepts in separate specific disciplines to inquiry-based learning in which students seek answers to questions that are driven by the learners' own curiosity, wonder, interest, or passion to understand and/or solve a problem (National Science Foundation, 1999). The pedagogy advocated for is an inquiry approach, in which students are actively engaged using both science processes and critical thinking skills as they search for answers. The National Science Education Standards (NSES), developed by the NRC in 1996, define inquiry in education as: "Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other source of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and communicating the results. Inquiry requires identification of assumptions, use of critical thinking, and consideration of alternative explanation." (p.23)

According to the NSES, there are five essential features of classroom inquiry: 1) learners are engaged by scientifically oriented questions, 2) learners give priority to evidence, which allows them to develop and evaluate explanations that address the questions, 3) learners formulate explanations from the evidence to address the scientifically oriented questions, 4) learners evaluate their explanations in light of alternative explanations, particularly those that reflect scientific understanding, and 5) learners communicate and justify their explanations (NRC, 2000). Science education reform calls for inquiry-based teaching methods that enable students to contribute their own ideas and to pursue their own investigations.

Inquiry begins when students are puzzled about some event or object, and then design and carry out an experiment to test their hypothesis. The process involves all the activities that a 'real scientist' uses to find information such as hypothesizing, conjecturing, reading, designing experiments, experimenting, collaborating with others, etc. Discourse is a means for inquiry, exploration, even activity, and expression of concepts. Using this approach requires that data be gathered, and interpreted. Students are required to draw conclusions based on the evidence they gather. The information learned through carrying out these investigations provides the opportunity for students to communicate their data and justify their conclusions. This in turn provides a means for students to get feedback from their peers, as well as the teacher, which can lead to students modifying their conclusions (this mimics the real scientific community). Research has shown that students, who carry out investigations to test their own ideas, or mental models, are much more likely to understand and retain the concepts learned.

Inquiry occurs when students are allowed to seek answers to questions for which they do not have answers. This does not mean that students have to discover everything on their own. As long as students are unaware of the relationships being investigated, students are carrying out inquiry-based science. Inquiry-based teaching begins with teachers who are willing to start with what students already know or "think they know" and to take the time needed to understand with what they are struggling. David Hawkins, philosopher of science has said that teachers must try to understand "the map" of children's minds (Hawkins, 1974). By carefully observing and listening, as students take part in investigations and discussions, teachers can come closer to knowing what students' conceptions or mental models are, as well as where they are struggling. Science is a social process, in which knowledge is constructed as students and teachers dialogue their understanding of science concepts with one other (Newton, Driver, & Osborne, 1999). The teachers' role is to drive the dialogue to the more scientific understanding.

Research has shown that alternative conceptions, or students' mental models, in science are often very difficult to overcome (Arnaudin, & Mintzes, 1985; Bishop, Roth, Anderson, 1986; Clement & Rea-Ramirez, 1997; Mintzes, 1984; Mintzes & Arnaudin, 1984; Sanders, 1993; Seymour & Longden, 1991; Songer & Mintzes, 1994, Rea-Ramirez & Clement, 1997; Rea-Ramirez, 1998). Learning is complex; it involves many changes in students' models as teachers and students work together to construct intermediate mental models (Buckley, 2000; Clement, 1989; Clement, 2000; Gobert, 2000; Gobert & Buckley, 2000; Harrison, 2000; Justi & Gilbert, 2000; Rea-Ramirez, 1999; Snyder, 2000; Steinberg & Clement, 1997). In the co-construction process, teachers guide students thinking through dialogue. Instead of presenting students with the scientific explanation, teachers build upon students' mental models. Teachers become a partner that guides the student in the co-construction of knowledge (Rea-Ramirez, 1998). In the process, teachers can use discrepant questioning to cause cognitive dissonance, which is required if students are going to modify their views (Clement & Rea-Ramirez, 1997).

Most middle school science curriculum has been created to provide superficial treatment of the different subject areas (earth, life and physical science), and in-depth coverage of very little. The Third International Mathematics and Science Study (TIMMS) criticism of the typical American school curriculum is that it is a "mile wide and an inch deep" (Schmidt, McKnight, and Raizen, 1997, p. 122). In contrast, "Energy in the Human Body" is an in-depth investigation of cellular respiration that is based on the National Science Education Standards. In this paper I will attempt to demonstrate how "Energy in the Human Body" has maintained the use of an inquiry-based approach into its curriculum.

Background

"Energy and the Human Body" is based on the NSES and many State Curriculum Frameworks in the area of middle school life science. It was designed using the latest research on how students learn and develop mental models. This information was used to develop methods for helping students learn material of fundamental importance to Biology. A cohort of dedicated classroom teachers and researchers who had many years of classroom teaching experience created the curriculum, which is based on sound theory and practical application that takes into account the developmental abilities of a variety of students.

In this curriculum, students learn about how their own body uses the energy they get from food. They learn why we breathe in oxygen, and breathe out carbon dioxide. They learn fundamental information about how their body works. Most importantly, they learn why their bodies are designed the way they are. Instead of memorizing vocabulary, students learn concepts of fundamental importance in later learning. Students have the chance to relate structure and function to help them understand how the way a part of the body is structured relates to the way it works.

Students are taught for deep conceptual understanding, through active involvement, using the knowledge they already have to construct new understandings. Teachers provide help in the form of questions that provoke thinking, as well as using analogies, demonstrations, hands-on science experiences, videos, computer animations, discussions, and student drawings to promote model construction. Teachers use the following series of steps to help students construct deeper understanding:

- Ask students what they already know
- Pose an open-ended question
- Have students think about the question, than share and compare the results of their thinking with others
- Have students discuss their ideas and come to consensus
- Challenge students' conceptual understanding using discrepant explanations
- Have students complete and articulate/draw their models
- Present the scientific model
- Have students complete their model revision by articulating/drawing their final understanding
- Have students compare their initial models with their final models
- Have students apply their knowledge to new situations

Throughout the curriculum students are engaged in small group work/cooperative learning. When students work in small groups/ cooperative groups they have the opportunity to present their ideas to each other and discuss them together. This helps students clarify their own understanding as they learn from one another. In addition, students are asked to draw their "mental models", this helps students clarify their thinking and it helps them create an image that can be revised. At times teachers' present misconceptions (wrong ideas) and through the use of discrepant questioning help students see the flaws in the misconception. At other times, teacher may use analogies to help students' ideas about difficult or unfamiliar concepts. This allows students to use ideas they already have to understand new ideas. In addition, teachers and students discuss the relevance of what students are learning to "personal life", this helps students see the usefulness of this curriculum to their real lives. Lastly, teachers use videos, animations, and other graphics to help students see the scientific model.

Inquiry in the Curriculum

Some of the ways "Energy in the Human Body" fosters an inquiry or 'active learning' approach:

- Students generate and improve initial models before the teacher presents the scientific model
- Discrepant questioning leads to student criticism and modification of models
- Learning through analogies, where students help flesh out the mapping or correspondence within an analogy
- Small and large group discussions

All of the above activities go far beyond a rote learning approach in their emphasis on student thinking as a means to learning science. "Energy in the Human Body" was designed to build upon students' prior knowledge. Students are constantly required to state their own mental models about how the human body works. As new information is presented it is interpreted through students' existing mental models.

At times students need to be made aware of discrepant information. It is possible for students to have simultaneous ideas that are contradictory. Only through reflection upon one's own thinking can change occur. With this in mind, this curriculum was designed to help students develop deeper understanding of cellular respiration through continually reflecting on their own mental models. In addition, students who use this curriculum are taught to value open-mindedness (a willingness to change ideas in light of contradictory evidence). This habit of mind is taught to students as they use this curriculum. As students use "Energy in the Human Body" they take on some of the attributes (values, attitudes and ways of thinking) associated with our scientific community. Through repeated occasions of social interaction with others (their peers, as well as the teacher) students collectively come to understand a phenomena or event as they explore cellular respiration.

Throughout this curriculum students are engaged in the process of inquiry (like real scientist) as they make predictions, classify, formulate models, make inferences, observe and measure, and interpret data. Lastly, the curriculum gives suggestions for individual and small group work that can give students experience with independent investigations.

Images of Inquiry Throughout the Curriculum

Chapter 1: Students start off by discussing different sources of energy that are used in everyday life to run things such as cars, lights, and household appliances. From there they move on to discuss the source of energy for their own bodies. They are asked to draw a model of what happens in their bodies as they exercise. They discover through classroom discourse that the body needs energy for all body processes. The teacher uses questioning strategies to provide scaffolding for students to build their own understanding. In addition, students working in groups also ask each other questions as they try to make sense out of each other ideas. The teacher acts as a facilitator, as students are actively involved and responsible for their own learning. Classroom discourse is an important component in the development of metacognition; students vocalizing their ideas may cause them to see the need to change their mental models.

Chapter 2: Students are asked to draw a model of what happens to food in their bodies. Drawing helps students clarify their thinking and helps them create an image or mental model. Working in small groups they discuss their models and come to consensus. Sharing with others causes students to reflect on their own model (metacognition) and others' models, which can result in restructuring their models. They discuss what food is made of and how it is broken down in the body. They learn that glucose is the source of energy for the human body. They are presented computer animations of the digestive system, which shows the path that food takes through our bodies as well as what happens at each site. One can consider the information presented in the animation as a type of alternative explanation (as some scientific explanations change over time as new information is uncovered). Students evaluate their models in light of the current scientific explanation. Working in small groups students discuss and justify their current model to their peers.

Chapter 3: Students are given a mystery box to find out how scientists learn about things that cannot be seen directly. The hands-on activity gets students interested in the topic and introduces some concepts that will be useful later. Students are asked to draw models that represent different kinds of cells (heart, muscle and skin) in the body. This gives students a chance to get their ideas on paper, and it allows teachers to find out what students already know. As students share their models with one another they are required to justify their ideas. Throughout the curriculum teachers are encouraged to use "what if" questions to help students construct new mental models. An example of a "what if" question that might be used by the teacher is: *"What if I could take a very thin section of the heart tissue – what would you see?"* Through the use of analogies (ear of corn and block wall) students discover that cells are found in patterned configurations in tissue. Analogies help give students ideas about difficult or unfamiliar concepts. Students learn they can use ideas they already have to help them understand new ideas. Analogies may help students generate new understandings of their ideas or mental models. They use a microscope to discover that cells are microscopic. The analogies used prior to using the microscope help students make sense of what they are looking at.

Chapter 4: Students are shown pictures of different kinds of cells (muscle, nerve, and skin). They are asked to compare and contrast these cells. They discover that cells have many common internal structures. Through the use of the "school analogy" students learn that structures inside cells have specific functions. The following "what if" question was used with a class of students to encourage model development through mapping and analogy and the cell: *"Look back at your drawing of the cell as if it were a school. In that model you said there would be chaos if you only had one big room where all the classes and gym and band took place. What if you and only had one big open space in the cell where everything took place?"* Questions like this make students think about their models and help them develop a deeper understanding. Questions in this curriculum rarely ask for factual information in the form of simple recall or memorized facts but rather encourage students to think deeper, to apply what they are envisioning. Students are asked to develop their own analogy for a cell and describe its similarities to a cell while giving the function of each major organelle. Students share their analogies with others. To assess their current understanding students are asked to create a three-dimensional model of a cell found in the human body, and write a story about being small enough to travel inside their cell. Students are given a rubric that shows how they will be graded on their projects.

Chapter 5: Through classroom discourse and small group work students discuss what cells need energy for. The exchange of ideas among students makes students' thinking available for inspection, and allows students to use their talk as a tool for thinking and communicating. Questions are used to help students recall prior experiences about what is needed for a fire to burn. Through the use of a "fire analogy" students discover that glucose is fuel for cells. The "popper simulation" helps students understand that when glucose is broken down in cells that energy is released which the cell can use for its needs. An animation is used that introduces the scientific model of how energy is released in the mitochondria. Students revisit their earlier model of mitochondria and revise it to incorporate newly presented information. Next, students construct a model of the structure of the mitochondria, to help them understand the importance of surface area of the inner membrane. This unit is culminated when students create a travel brochure about travel to the center of a cell. This activity allows students to demonstrate their understanding of cells in a variety of ways including writing, an important tool of communication in science.

Chapter 6: Students draw models that depict their understanding of how oxygen and glucose are delivered to cells, and how carbon dioxide (a waste product) is removed from cells. Drawing models allows students to contribute their own ideas. Working in small groups they come up with a consensus model. The teacher shows them an animation about how blood circulates in the body. The animation is a springboard for classroom discourse. If students cling to the misconception that the circulatory system is an open system, teachers are encouraged to use discrepant questions and more analogies to help students understand that it is a closed system. Students revise their models to incorporate new information that may have been presented. Next, the "river delta" and "water pipe" analogies are used to help students understand the function and structure of different types of blood vessels. Analogies are a way for teachers to humanize science. Teachers use analogies to help clarify an idea, or develop a concept, which may lead students to revising their mental models. An animation of blood vessels is used to present the scientific model. Classroom discourse and small group work allows students to criticize and revise their own models. The scientific model is not introduced until students have had the opportunity to work through their own ideas about how this model might work. Students conduct hands-on investigations to learn about diffusion, which helps them understand how glucose moves from the blood into cells.

Chapter 7: Students draw models that show how oxygen gets from the air they breathe into their cells. Drawing helps students make their models more accessible. Working in small groups they come to consensus. All students in the group are required to be able to defend their model. Next, they draw models of their understanding of the structure and function of the lungs. Through discussions with others students learn that others may have different models, this may lead some to revise their own models. They conduct hands-on activities to measure the volume of air in their lungs and use this information to revise their models. Mathematics is used to calculate surface area. The "grape analogy" is used to help students think about the structure of the lungs. After students examine pig's lungs they criticize and revise their own models. An animation is used to present respiration. It is important to note that students do not give up their models just because they have been presented with the scientific model. In order for students to revise their models they must see that their model cannot be used to explain certain situations.

Chapter 8: Students draw models of how the heart and lungs work together to deliver oxygen, and glucose to cells and carbon dioxide away from cells. Students are encouraged to challenge each other's models to see if they have flaws in them. Working in small groups they come to consensus. Students are asked to design a heart that transports oxygenated blood to cells and carbon dioxide rich blood away from cells. They share their models and revise their own mental models. It is important that the scientific model not be presented until all suggested models have been discussed and criticized. Next, they watch an animation about the structure and function of the heart, and revise their models one last time based on which model seems best.

Conclusion

Overall, "Energy in the Human Body" uses an approach designed to help teachers find out what students already know (this engages students), and to identify what questions students have (inquiry should involve students looking for answers to their own questions). The curriculum uses students' prior knowledge and questions to direct its implementation in classrooms. This is in sharp contrast to most middle school science curriculum material, which often does not start with students' current understanding of concepts nor does it take the time to find out what questions students would like to seek answers to.

Inquiry in the middle school science classroom can take many forms. Some activities in "Energy in the Human Body" are highly structured while others are more open-ended. Both have value in middle school science classrooms. Overall, an attempt was made to develop students' natural curiosity throughout the curriculum. Classroom discourse was an important component. As students work in small groups the teacher listens to students and learns about students' knowledge deficiencies and misconceptions. Lessons are exciting and motivating as students engage in conversations about science that is relevant to their lives. Allowing students to share their knowledge with one another creates a student-centered environment that empowers them to learn more about a given topic. Because students themselves explained what they knew about respiration, they are more likely to retain that information.

This curriculum identifies, builds on, and when necessary, consciously challenges students existing mental models. It provides opportunities for students to learn that are built upon their interest, questions, curiosity and existing knowledge. Students are constantly engaged in making sense out of situations. Students are required to be reflective and revise their thinking; self-assessment is used to help students reflect upon their own thinking. Students are given opportunities to apply their skills and understanding in new situations. Students spend a great deal of time collaborating with others to come to consensus. Students learn from one another, as they learn content in a positive environment that values all learners' opinions.

Middle school science teachers need more high quality instructional materials like "Energy in the Human Body" that were developed based on research about how students learn. This curriculum helps teachers understand how particular conceptions typically develop, as well as confusions that may arise. "Energy in the Human Body" gives students multiple opportunities to change their thinking and develop deeper conceptual understanding. In addition, the teachers' manual is designed to help teachers understand the pedagogical approach required to make this an effective curriculum.

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DEVELOPING AN AUTHENTIC LANGUAGE FOR A WEB-SEARCHABLE, HYPERMEDIA TEACHER –EDUCATION-DATABASE

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Overview

Several factors point to the need to explore alternative technology solutions for teacher education, including mitigating science teacher shortages, supporting novice teachers and their mentors, and helping to ensure continuous professional development of inservice teachers.

Teachers and teacher educators currently have access to such searchable repositories as the Educational Resources Information Center (ERIC, http://www.ericse.org/), the Eisenhower National Clearinghouse for Mathematics and Science (ENC, http://www.enc.org/). Teachers are familiar with the thesaurus and descriptors these databases use to structure their searches. But at present, both databases are limited to printed text and graphics, and do not include media, such as sound recordings, digital images, or recordings from video tapes, laser disks, compact disks (CDs), or digital video disks.

Technology today supports integration of media with text-based resources. For example, *SciLinks* enables teachers to locate resources specific to the textbook. Teachers go to the *SciLinks* web site and input one of the codes that is printed throughout their textbook. Teachers need this code to access the resources on the Web annotated in their textbook.

Moreover, the Internet offers untold other resources and supports multimedia capabilities and hyperlinking. Well-designed web sites provide navigation tools that facilitate within-site information location, and many contain hyperlinks to other Internet resources. In addition, we now have powerful web browsers capable of searching across and within Internet sites to locate information. At present, however, these perform non-discriminatory, literal searches that seek to match user terms with language from online text or found embedded as metatags (key words). Thus, even though technology enables a teacher or teacher educator to "locate" a lot of information, the results must be winnowed to separate appropriate from inappropriate resources.

At present, teacher educators do not have a searchable database that provides access to multimedia instructional resources. As an example, teacher educators do not have a way to readily search for specific kinds of sequences within videos depicting classroom practices. A teacher education database might include such categorizes as examples of direct teaching and inquiry approaches, of differentiating instruction, or a host of other topics relevant to teacher preparation and professional development. Such a database should not only be designed specifically for teacher education, but also be easy to use both in classrooms and at home as a personal learning tool.

Creating a searchable multimedia teacher-education database requires a thesaurus control language for categorizing and labeling sequences in multimedia artifacts. This language must be based on a conceptual hierarchy that is authentic to teacher educators and teachers, and also capable of meeting the constraints of computer programmers. Our present work aims to develop such a database. One aspect entails developing an authentic language for teacher education capable of embracing the richness of text, multimedia, and hypertext, and also for supporting archiving functions so that educators can add as well as access resources. This paper looks at a key aspect of developing that database, the language needed for categorizing and retrieving information. Essentially, the challenge entails identifying or developing a language that is authentic to teacher education and teachers, appropriate for coding text and multimedia resources, and compatible with computer programming requirements.

Prototype Databases

Arguably, the best approach for explaining our present database work is to describe in more detail how it stems from our prior efforts and progress in developing computer-assisted multi-media solutions for science teachers. One of the earliest of our efforts grew out of the need to enrich and enhance *The Fluid Earth* (Klemm, Pottenger, Speitel, Reed and Coopersmith, 1990) and *The Living Ocean* (Klemm, Reed, Pottenger, Porter, and Speitel, 1995). These textbooks book are part of the constructivist Hawaii Marine Science (HMSS) program, which was developed at the Curriculum Research and Development Group in the College of Education at the University of Hawaii. They have been adopted and used by teachers throughout the U.S. mainland and Pacific, and received national recognition for their inquiry-based, "hands-on, minds-on" approaches to teaching and learning. For the most part, the HMSS materials are disseminated via HMSS teacher workshops.

HMSS students are actively engaged in learning throughout the program, and they learn content through the inquiry process, not from reading text. The HMSS activities engage students in examining marine specimens and realia, and in constructing and testing maps, models and simulations. A characteristic of the marine sciences is that they study real-world phenomena, much of which can readily observed using photographs, videos and other visual and audio recording devices. The coupling of computers with satellite and underwater technologies made imaging and computer simulation important tools used by those who study the oceans. However, the two HMSS books are print-based, with black and white graphical illustrations of procedures and few diagrams of concepts, the later by design because the focus is on students engaging in inquiry.

Teachers using HMSS are encouraged to responsibly collect and use marine realia (Klemm, 1990). Although the basic ideas in the HMSS program can be taught and learned successfully with relatively few resources, visual images in particular greatly enhance not only the concepts being learned but also their connection to real world marine contexts.

Thus, a CD was developed containing visual and audio enhancement of the two HMSS books. Development of the CD was undertaken to address the needs of teachers in inclusive marine science classrooms (Speitel, Iding & Klemm, 1999) The CD was designed so teachers could readily locate resources appropriate to specific portions of the HMSS books. For example, the CD provides audio pronunciation of new terms, given together with images (drawings, digital images or video) to illustrate them. The CD contains many images of plants, animals and environments studied in HMSS. It also provides enrichment of the text in the form of digital images and video of specific phenomena (e.g., a whale breaching) and procedures (e.g., how to make fish prints or use an orange to make a globe of the world).

When HMSS classroom teachers used the CD, they liked having access to multi-media, program-specific resources, but also wanted to be able to easily link these with other Web resources. Thus, the School Web of Instruction Media (SWIM) database was created, putting the CD onto the Web. SWIM provides a searchable database that allows for easy access to instructional resources pertinent to HMSS, with different levels of access for teachers and their students. The media resources included in the SWIM database are directly linked to specific activities and pages in HMSS books. Included in this database are images, pictures, video, sound, text and computer programmed materials, plus examples, translations, definitions, quizzes, further explanations, and interactive animations and simulations.

HMSS educators and scientists searched through the Web to locate and review resources appropriate to specific concepts, processes or environments investigated in the HMSS program. The materials in the original HMSS CD disk (which is no longer available) are all now available through the SWIM database, and these have been further augmented with carefully selected hyperlinks to other web-based information. Teachers who use SWIM can also contribute to the database. The resulting SWIM database is a searchable multimedia connectivity database. It does not contain the images or multimedia, but instead, serves as a search vehicle capable of connecting the use to pertinent, selected resources (including CDs and other Web sites). Resources are selected by content experts and experienced HMSS teachers. These selected resources are useful to a wide range of students and teachers who are interested in marine science topics and activities, not limited to just those using HMSS.

From our experiences in creating SWIM, we realized that such a database could also be developed to provide teacher educators and teachers with searchable access to examples of content, pedagogy and assessment. Thus, work on SWIM led to our present work in developing the Teacher Education Component of the SWIM database (TEd-SWIM).

Relevance to Science Teacher Education

The need for a web-searchable, multimedia teacher-education database is particularly compelling for several reasons, including those reported by Darling Hammond (1997, 2000a, 2000b) as existing shortages of science teachers, expected large numbers of retiring inservice teachers, the hiring of under-qualified teachers, the exodus of too many novice teachers from classroom teaching, and the lack of qualified mentors or support for mentoring. Needs include helping teachers develop a repertoire of teaching and learning strategies, including constructivist teaching approaches; facilitating their development of competencies for enhancing science instruction with technology (Harry & Carbonne, 2000); and supporting their efforts in creating learner-centered, resource rich learning environments (Bodzin, 1998).

The Teacher Education Component of SWIM (TEd-SWIM) that is discussed in this paper is currently in prototype development and testing, building on the capabilities of the original, tested SWIM database. According to Klemm, Iding, Speitel and Nuygen (2002), a teacher education database should have these capabilities:

1. Support the developmental stages in teacher preparation and professional development;

2. Address standards for teacher preparation and teaching (See Appendix);

3. Offer multiple strategies and models for teaching and learning, including behaviorist and constructivist approaches, which exemplify research-based validated practices,

4. Include the subject matter, pedagogy and pedagogical content knowledge of science teachers and teacher educators in a way that addresses their instructional needs (e.g., developmentally appropriate, differentiated instruction);

5. Model integrated instructional technology practice to enhance learning, productivity, and creativity (International Society for Technology in Education, 1996, 1997); and

6. Embrace an authentic language for theory and practice, and use this for developing a virtual professional development database for teachers.

A salient question in developing this language is "authentic to whom?" Hence, we are now in the early stages of designing a prototype language for the TEd-SWIM database. Our development team includes experienced teachers and teacher educators as well as instructional designers, computer programmers and computer engineers. Our work entails envisioning the users and their needs, and designing prototypes of a language structure that makes sense to them. We will embed this language visibly in the search options and invisibly in categorizing and cross-linking media resources. This language syntax must be familiar and useful to teacher educators and teachers, and also be compatible with the constraints imposed by computer programming logic.

Theoretical and Methodological Background

Research reported by others engaged in similar work forms a theoretical foundation for our work. Harry & Carbonne (2000), Lewis & O'Brien (1998), Lewis & O'Brien (2001), and Zembal-kSaul, Boardman & Dana (2000) report on merits and limitations of multi-media, web accessible teacher education and professional development, which we consider in our design. We also look for use of language in research on telecommunications for networking and electronic professional development (Bodzin & Park, 1998; Bodzin, 2000; Hammer & DiMauroLavole & Foster; MaKinster, Barab & Keating, 2001; Spector, Burkett, Barnes & Johnson, 2000; Whitworth, 1999) and at the nature of sites related to web-based curriculum design (Bodzin, Wilson & Hug, 2000; Spector, Burkett, Barnes & Johnson, 2000). In addition, we have been examining our own experiences in teaching undergraduate and graduate education courses, including our actual and potential future use of media.

Working in small focus groups, we are in the early stages of identifying terms and deliberating on ways to group them, a necessary step in order to design Web pull-down menus, and within-site links. We began testing preliminary ideas for our database language, testing how we would use terms when viewing videotape segments of science teachers and students engaged in teaching and learning. As we do so, we test the adequacy of our evolving language set to see whether it addresses the intended use of the video or other media. We also consider how that video segment might be repurposed. For example, a video segment depicting inquiry could also be used to show a way for organizing and managing a science classroom to support inquiry. We are currently seeking funds to support this research and to involve other educators in the development of this database. Support to date came from federal, state, and University of Hawaii funds.

The TEd-SWIM database is in its early design and prototype testing stages. Although it currently focuses on science education, we believe that if we are successful and the language system we develop is authentic to science teacher education, that much of it will be applicable to other areas of teacher education as well. Persons interested in our work are encouraged to visit the original SWIM database, which is available at http://www.hawaii.edu/swim/.

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Appendix

Standards for Teachers and Teaching

The Interstate New Teacher Assessment and Support Consortium Standards
(Available: http://www.ccsso.org/acadfact.html)

The National Board for Professional Teaching Standards
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USING THE LEVELS OF ACCESSIBILITY MATRIX SYSTEM TO PROMOTE PRESERVICE SCIENCE STUDENTS' THINKING ABOUT INCLUSIONARY TEACHING

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Overview

General education teachers identified science as the subject area most amenable for mainstreaming students of all disability categories (Atwood & Oldham, 1985); and special educators identified science as a subject that is particularly useful for many students with disabilities (Hadary & Cohen, 1978; Mastropieri & Scruggs, 1992; Mastropieri & Scruggs, 1994; Patton, 1993; Patton, 1995; Scruggs & Mastropieri, 1993, Mastropieri, Scruggs, Magnusen, 1999).

Science is preferred when it uses constructivist approaches such as the Learning Cycle, which combines exploration, convergent instruction, and divergent reasoning into a guided discovery strategy. Such an approach offers many opportunities for differentiating instruction and accommodating learner needs (Norman & Caseau, 1995; Stefanich, 1998). Activities-based, guided discovery approaches promote thinking, and foster problem solving abilities (Masteropieri & Scruggs, 1992; Woodward, 1994). These approaches also offer multisensory learning experiences, which are supported by research on the brain and cognition.

The two notions that are key to successful inclusion of students with disabilities are views about disability and actions taken to make learning fully accessible. Traditionally, disability was viewed as the limitations inherent in handicapped individuals. Today, the preferred view of disability is one of enablement, a positive ecological view of disabilities as the limitations to full participation that result from inaccessibility of physical environments as well as the lack of accommodation, support, or inclusion in social environments (Daniels, 1990; Enders, 1999; National Institute on Disability and Rehabilitation Research, 1998; and Seelman, 1998). A commonplace example is illustrative: ramps at curbsides make environments accessible to those with disabilities, and also enable others, e.g. parents with strollers, or children with skate boards.

Our research focuses on enablement in the form of actions taken to make hands-on science activities accessible to all students. We do not address the physical arrangement of the lab (e.g. the height of tables), nor the critical thinking skills and cognitive processing involved, although both are necessary. Instead, we focus on the nature of the activities themselves. In this paper we report on our work in developing and testing the Levels of Accessibility Matrix system as a heuristic devise to prompt preservice teachers' thinking about the accessibility of hands-on activities when considered through the lens of multisensory and manipulative opportunities, and about ways to select or modify hands-on activities to enable learners to use their abilities.

The Levels of Accessibility Matrix System

Here we report the continuation of our research on the Levels of Accessibility Matrix (LAM) system, a way to evaluate the sensory and motor/manipulative accessibility of hands-on activities (Klemm & Laszlo, 2001). As shown in Table 1, the LAM matrix is organized with sensory inputs arrayed horizontally and types of impairments, vertically. Using a rating scale of 0 (completely inaccessible) to 4 (completely accessible), we analyze the kinds of sensory and motor abilities needed by learners to fully engage in the learning experiences associated with a specific hands-on inquiry laboratory activity.

Table 1.

Sample Levels of Accessibility Matrix Table

Disability	Visual Input Accessibility	Tactile Input Accessibility	Auditory Input Accessibility	Motor Requirements Accessibility
Profound hearing impairment/deaf				
Visual impairment/blind				
(List other disabilities)				

Note. Scale for rating levels of disabilities:
0 = Not Accessible (even with lab modifications and personal assistance)
1 = Might be Accessible (with lab modifications and personal assistance)
2 = Accessible (with lab modifications and personal assistance)
3 = Accessible (with lab modifications, no personal assistance required)
4 = Fully Accessible (without lab modifications or personal assistance)

We initially devised the LAM system out of our need for a way to select hands-on science inquiry activities for a science camp for youth with disabilities (Klemm, Skouge, Radtke & Laszlo, 2001). We then wondered about the utility of the LAM system for helping preservice teachers to plan ways for making hands-on activities accessible to all learners, including those with disabilities.

We tested the effectiveness of the LAM system on preservice teachers in two science methods classes: a secondary science methods class (22 students) taught by the first author, and an elementary science methods class (28 students) taught by the second author. In each class, the preservice teachers were randomly divided into expert teams, with each team assigned one of the following disability categories, accompanied by a brief definition of the category: Hearing impairment or deaf; Vision impairment or blind; Speech or language impairment; Orthopedic impairment (defined here as confined to a wheelchair.) All teams were given a tuning fork and a slinky, together with a few guiding questions to initiate exploration of sound, the first part of the Learning Cycle approach. Each methods student was asked to separately evaluate the accessibility of the activities for learners with the assigned disability, then to compare and discuss the ratings within the team. Each expert team reported to the whole class, followed by class discussion of ways for making the activities accessible to all learners.

Both LAM sessions began with a three-part focused-write activity asking the preservice teachers to explain sound, suggest ways to teach sound using hands-on activities, and suggest ways for making sound accessible to students with disabilities. The instructors then very briefly demonstrated the tuning fork, the slinky and other supplies that the teams could use. Working in expert teams, the students explored freely with ways to use the equipment to teach sound.

Students were told that the LAM system was an experimental idea that the instructors were trying in order to learn how to better plan for accessible hands-on instruction. Each student was asked to voluntarily provide written background information on prior experience in teaching students with special needs and on prior experience with these specific sound activities. All students agreed. They also completed and turned in their written notes on LAM worksheets which prompted thinking about the kinds of sensory or motor experiences related to the activities, and about the abilities or limitations of the assigned disability. Teams worked to carry out the activities and devise modifications. Then, based on the assumption that they would implement these modifications, they were asked to re-think the accessibility of the activities for their assigned type of learners with disability. In addition, all the methods students were asked to think about and respond in writing to open-ended questions that we discuss in the next section on findings.

Findings

Responses were tabulated and examined at both the individual and "expert group" levels to determine whether the LAM system was effective in fostering thinking of preservice teachers about making the sound activities accessible for learners with disabilities. We knew that the secondary science education methods students had more science coursework than the elementary methods students, but found them somewhat less familiar with the hands-on science activities using tuning forks and slinkies than the elementary students (83% unfamiliar in the secondary, 73% unfamiliar in the elementary group). The data showed that 33% of secondary and 88% of elementary preservice teachers had prior or concurrent coursework or experience in special education. Here we authors note that both groups are required to complete a course in special education, and that these responses reflect differences between groups as to when that course is taken in the respective teacher preparation programs.

We compiled and then coded the responses to open ended questions, which we discuss here. Initially, the preservice elementary teachers, who had more prior special education background, gave far more specific suggestions for possible accommodations to the activity than did the secondary group. Their responses indicated that they were thinking and writing about the needs of an individual student with a specific disability, and what might be needed for that particular learner to succeed. The secondary preservice teachers' initial responses also indicated that they anticipated that students with hearing, sight or orthopedic difficulties might need personal assistance, and that some sound activities might be difficult for students to do, but they were less specific in their comments. Other than suggestions for an assistant or peer to help in manipulating equipment, only one secondary preservice teacher wrote about using the sense of touch to feel sound vibrations as a way to perceive sound. By comparison, several in the elementary group anticipated being able to use visual and tactile stimulation, as well as sound.

Responses to the post-LAM activity also indicated some difference between groups. The secondary and elementary teachers' respective responses to the question "Who should decide whether or not an activity is accessible?" were as follows: the student (25%, 10%); the teacher (42%, 20%); and both student and teacher (25%, 70%). Here, the secondary group favored a greater role for the teacher, and the elementary group, a shared role between teacher and student with disability.

To the question "Must all students be fully included in all activities?" more than half of both groups said "yes" (secondary, 54%; elementary, 59%). The remaining students differed in their responses, with 23% of secondary and 41% of elementary saying "as much as possible" and 23% of secondary and 0% of elementary saying "no."

A closely related question "Should some activities be eliminated if they are not fully accessible elicited a definite 92% "No" response from the secondary preservice teachers, and 55% "No" plus 41% "It depends" responses from the elementary preservice teachers. Their reasoning was clarified further in the final question, "Under what circumstances might you do an activity that is not fully accessible to students?" Responses in both groups (44% secondary, 20% elementary) indicated that some would do a lab activity if it were needed in order to understand a concept or process. Others (22% secondary, 25% elementary) responded that they would provide alternative activities or roles for certain students. Yet others (33% secondary, 15% elementary) indicated that they would do the activity if special needs students are absent, or not included (specifically mentioning hiking), or excluded entirely.

When asked "As a result of this exercise, what did you learn today that was useful?" the data showed that the LAM coding system provides a way for preservice teachers to scale and later talk about their ideas both with respect to the stimuli in the sound activities and the abilities of students to perceive sound, touch and sight. Thus, the LAM system provides a way to focus on the nature of the hands-on learning experience, as well as the needs of specific learners with disabilities. Their written comments indicated that the LAM activity facilitated their thinking about "how and why modifications/accommodations should be made for hands-on activities" and that "It required me to think about the sound/hearing process." Further, the LAM approach showed them "how to look at a specific task or project with a specific disorder in mind." Moreover, LAM "got us thinking about how we would make the props accessible to the students."

When asked whether the LAM approach should be included in future methods courses, all responses indicated "yes." One student said I learned that "almost all activities are accessible to students with disabilities if some modification is made to involve all senses in the activity." Another, "I never would have imagined that a hearing impaired student would be able to see and feel frequency in that way."

From the data, we noted that in the post-LAM responses, the secondary preservice teachers became more specific in their suggestions about how the sensory features of the lab activities are important as perceptual stimuli for students. We believe this indicates that the secondary group, who had less prior special education background, were prompted as a result of LAM to think more specifically about both the features of the lab activity and ways of accommodating students. A number of the responses from the elementary teachers were more general, in contrast with the specificity of their pre-LAM responses. Although the elementary responses were more general, they were more enthusiastic. One possible explanation is that because the elementary teachers had already written more specific suggestions for anticipated accommodations in the pre-LAM activity, they might have felt that they did not need to repeat themselves, and so they responded more in terms about how they felt about the LAM experience.

We conclude from the data that the LAM system was effective for prompting elementary and secondary methods students in thinking about the sensory nature of hands-on activities and how the activities can be selected and modified. The LAM system also prompted discussion about ways to provide accommodations for learners with special needs so that they can be successfully and fully included in hands-on science learning.

Discussion

Standards for teaching and for teacher education call for inclusionary teaching practices. Both the *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) call for "science for all." These science education standards have been incorporated into the standards for teachers and teaching listed in the Appendix.

Laws related to special education mandate the inclusion of students with special needs in "least restrictive environments" so that they receive appropriate accommodations. The laws identifying students with disabilities include IDEA 97, the Americans with Disabilities Act, and Section 504 of the Rehabilitation Act of 1973. Other provisions for special education are found in the Education for All Handicapped Children Act (1975 P. L. 94-142; 1986 P. L. 99-457; the Individuals with Disabilities Act of 1990 P. L. 101-476, and1997 P. L. 105-17).

Knowing that science is one of the areas favored for placement of special education students means that science teacher educators must work with elementary teachers and science teachers to help them plan for accessible accommodations in science learning activities for inclusive (mainstreamed) classes. Science teacher educators must also work with special educators to help them better understand the inquiry-oriented nature of activity-based science learning. Meyen & Skirtc (1994) identified the various settings where special educators teach science or interact with regular education teachers who teach science. All these teachers have in common the need to use inquiry-learning strategies effectively with all students. Thus, all confront questions about accessibility.

We contend that the LAM system complements thinking about use of assistive technologies (e.g. modified computers, Braille devices or talking devices) to help learners with special needs. Two excellent examples for using assistive computer technologies and principles of universal design for learning are found in the CAST (Center for Applied Special Education Technology, Available: http://www.cast.org) and in the DO-IT (Disabilities Opportunities Internetworking Technology, Available: http:.//www.washington.edu/doit) web sites.

To our thinking, not made explicit in these approaches is what we have called the LAM system, a systematic way to determine the sensory stimuli inherent in a hands-on activity. The LAM activity prompted discussions about amplifying stimuli or searching for alternatives related to the concept of sound that involve touch and sight as well as hearing. The LAM activity also prompted discussion about the perceptual and manipulative requirements of the activities and the abilities of learners. Discussions of accommodations included what could be done to modify or enhance the lab activity so that the concept or process being taught can be understood through the full range of sensory modalities. Discussions also addressed ways to help students with assistance in manipulating equipment, an in contributing to group investigations, as well as helping them use all their senses to learn.

Future Research

In future papers we will report on the continuation of our research to use the LAM system with inservice teachers and with a wide range of science activities. We believe that a LAM analysis of an activity provides useful information for teachers to use in selecting activities and alternatives, in modifying instruction, as in as pairing specific students who can help each other, and in using augmentative technologies to help students gain and demonstrate knowledge. We further believe that the LAM system provides teachers with information from which to base instructional approaches using best practices for all students, with or without disabilities. .

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Appendix

Standards for Teachers and Teaching

The Interstate New Teacher Assessment and Support Consortium Standards (Available: http://www.ccsso.org/acadfact.html)

The National Board for Professional Teaching Standards (Available http://www.nbpts.org/)

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IMPACTS OF CONTEXTUAL AND EXPLICIT INSTRUCTION ON PRESERVICE ELEMENTARY TEACHERS' UNDERSTANDINGS OF THE NATURE OF SCIENCE

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Science educators have identified the development of accurate understandings of the nature of science as an instructional goal for nearly a century (Lederman, 1992). Despite the longevity of this instructional goal, research has consistently shown that K-16 students do not attain desired understandings (Duschl, 1990; Lederman, 1992, among others). One explanation for students' lack of success in learning current conceptions of the nature of science in K-12 classrooms is that the vast majority of elementary and secondary teachers rarely address this topic explicitly in their science instruction. Much of this failure is due to the lack of emphasis on the nature of science in the science courses of many teacher preparation programs. However, even programs emphasizing the nature of science as a theme have met with limited success in facilitating preservice teachers' abilities to understand and teach this elusive construct (Abd-El-Khalick, Bell, & Lederman, 1998; Akindehin, 1988; Author, 2000; Haukoos & Penick, 1983, 1985; Olstad, 1969; Scharmann & Harris, 1992). One possible explanation for the insufficiency of these programs is the uncontextualized manner in which they address the nature of science. With science instructors unlikely to focus on the nature of science in content courses, the nature of science lessons are generally relegated to the methods courses, where they are typically presented out of context as an add-on to the science curriculum (Driver, Leach, Millar, & Scott, 1996). When addressed in this manner, preservice teachers may see the nature of science as supplemental, rather than integral to their science instruction.

Current science and technology based issues such as global warming present the "messiness" of science-in-the-making and bring students into direct contact with the values, assumptions, and concepts embodying the nature of science. Furthermore, science and technology based issues situate lessons about science in the context of learning relevant science content. In many cases, these issues can be presented as subunits within a typical science methods course, eliminating the often-difficult task of finding science professors willing and able to tackle the nature of science in their content courses. Thus, many have argued that science and technology-based issues provide an ideal context for enhancing students' and teachers' understandings of the nature of science (Bentley & Fleury, 1998; Collins & Pinch 1998; Spector, Strong, & La Porta, 1998).

The Nature of Science

Although there is some disagreement regarding the specifics of the nature of science, there is an acceptable level of generality regarding the nature of science upon which the majority of experts agree and which is relevant and accessible to K-12 students (Lederman & Abd-El-Khalick, 1998; Smith, Lederman, Bell, McComas, & Clough, 1997). Included are the concepts that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory-laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), and socially and culturally embedded. Two additional aspects focus on the distinctions between observation and inference and the role and distinction of scientific theories and laws. This characterization of the nature of science is supported by current science education reform documents (American Association for the Advancement of Science, 1993; National Research Council, 1996), and it provided a conceptual framework in the present investigation. For a more detailed description and justification of this characterization, see Lederman, Abd-El-Khalick, Bell, Schwartz, & Akerson (2001).

Method

Purposes

The purposes of this study were to assess (a) the influence of instruction on a controversial science and technology based issue (global climate change and global warming, or GCC/GW) on elementary preservice teachers' understandings of the nature of science, and (b) the relative effectiveness of an explicit approach versus an implicit approach to the nature of science instruction. To this end, a matrix of the nature of science and GCC/GW instructional treatments were employed over a period of four semesters (Table 1).

Table 1

Treatments by Semester

Semester	Treatment	# of Participants
Spring 2000	GCC/GW, explicit NOS	15
Fall 2000	No GCC/GW, implicit NOS	20
Spring 2001	No GCC/GW, explicit NOS	18
Fall 2001	GCC/GW, implicit NOS	22

Participants

The study involved all elementary preservice teachers enrolled in a required three-credit elementary science methods course at a major mid-Atlantic university. In total, the participants numbered 75 (70 females, 5 males), with ages ranging from 21 to 38 years. Most were fourth-year students enrolled in a 5-year BA/MT program. The majority (89%) were liberal arts majors, with the other 11% majoring in science or mathematics. The MT program has a rigorous admissions policy focusing on GPA, GRE scores, and prior experience working with children. The consistent application of the MT admission criteria facilitated homogeneity of aptitude and achievement across treatment groups.

The Intervention

The controversial science issue selected for inclusion in the elementary science methods course was global climate change and global warming (GCC/GW). In the semesters when GCC/GW was taught, approximately 7 hours of class time were devoted to this instruction. Assignments included readings and discussion from popular periodicals and climatology literature, as well as hands-on inquiry activities related to GCC/GW (see Matkins & Bell, 2001 for a description of these activities). Additionally, environmental science faculty who were specialists in climatology met twice with the preservice teachers in small group settings to discuss current research findings and applications in the K-8 classroom.

Preservice teachers who received explicit nature of science instruction participated in a set of five inquiry-based activities taken from Lederman & Abd-El-Khalick (1998) and Lederman, Abd-El-Khalick, and Bell (2000) and a discussion of one reading assignment (Springston, 1997) selected to teach the seven target aspects of the nature of science. The preservice teachers participated in class discussions focusing on relevant nature of science aspects following each activity. Furthermore, in the nature of science with GCC/GW treatment group, the instructor encouraged the preservice teachers to relate characteristics of the nature of science to GCC/GW concepts as they were being taught.

Preservice teachers in the implicit nature of science instruction groups participated in none of the explicit nature of science activities in order to limit the potential source of changes in their nature of science understandings to implicit sources (either the GCC/GW instruction and/or the inquiry-based methodology promoted by the elementary science methods course).

Data Collection

Data sources included pre- and post-questionnaires, interviews, relevant course assignments, and electronic journal entries. The nine-item open-ended questionnaire used to assess understandings of key elements of the nature of science and GCC/GW was based on the Views of Nature of Science questionnaire (Lederman et al., 2001). Five items focused on the previously mentioned aspects of the nature of science and four items related to GCC/GW. Following each administration of the questionnaire, six participants were interviewed to help establish validity of the questionnaire responses. Preservice teachers were purposefully selected for interviews to produce a stratified sample based on the available range of science backgrounds (from few to many secondary- and college-level science courses). During the audiotaped interviews, participants were asked to explain and elaborate on their responses to the questionnaires.

Data Analysis

In analyzing the data, the researchers have sought to provide rich descriptions of the beliefs of a limited number of participants based upon qualitative data, rather than less detailed treatment of a much larger sample. The descriptions will include excerpts from the preservice teachers' assignments, journal entries, questionnaire responses, and interview transcripts. It should also be noted that due to the participation of all students in the four semesters of the investigation and the inability to randomly select from among all preservice elementary teachers, it made most sense to treat the participants as the population, rather than a sample. What this approach loses in terms of generalizability, it gains in authenticity (generalization from such a small, nonrandom sample makes little sense). Thus, this investigation may be seen as an initial attempt to frame the issues and as a foundation for future research.

The various data were first analyzed individually using Bogdan and Biklen's (1992) model of analytical induction and then together in order to test the validity of developing assertions. In this approach, working hypotheses to describe/explain the participants' views were continually formed and then tested against subsequent data. The ultimate goal was to develop generalized profiles for the preservice teachers' nature of science and GCC/GW understandings derived from systematic examination and re-examination of the available data. The variety of data sources permitted the triangulation of data and supported the validity of the profiles of each apprentice's understandings and apprenticeship experience. Finally, participants' profiles were compared to assess changes in the nature of science and GCC/GW understandings, and overall gains were compared among all treatment groups to assess the relative effectiveness of the four instructional approaches. Since two researchers analyzed the data, it was necessary to establish inter-rater agreement prior to the analysis of the entire data set. The researchers accomplished this through systematic comparison of separate analyses of three randomly selected data sets, with the end result of 90% agreement.

Results and Discussion

Results of the analyses of the preservice elementary teachers' responses to the questionnaire and follow-up interviews indicated significant pre- to posttest differences in their views of the nature of science and global climate change when those topics were explicitly addressed in the class. Overall, in the semesters where nature of science was taught explicitly, the posttest responses reflected current understandings at a substantially higher rate than those of the pretest (Table 2). Each data table is followed by a summary of pre and posttest responses and by representative quotations. The coding system used in the following sections delineates whether specified data were collected prior to (Pre-) or after (Post-) and to identify individual participants (1 to 22). The concluding component of the coding system is the semester in which the individual was in the class (Spring/Fall, 2000/2001).

The Nature of Science

Pre-Instruction Views of the Nature of Science

The preservice teachers' pre-instruction responses reflected common misconceptions about the nature of science. For example, the majority viewed scientific knowledge as absolute truth. All participants believed that theories become scientific laws when proven true, and most were unable to explicate roles for imagination, creativity, or social influences in the development of scientific knowledge (see Table 2).

The Empirical Nature of Scientific Knowledge

The level of understanding of the empirical nature of science was consistently low across all semesters. Most of the participants were familiar with the use of evidence in science, and referred to scientists' use of observations and data. However, most also indicated that data and observations are the sole source of evidence, and that scientists use data and observations to *prove* their theories and conjectures. The roles of creative thought and the development of inferences in the establishment of scientific knowledge were not mentioned by most participants

> A scientific theory is an idea that has been tested and scientists are still testing to prove the theory as true.... A scientific law is a theory that has been tested and proven. (Pre-1, Spring 2000)

> I think that theories sometimes change. Using new technology scientists are able to find out more and more information regarding scientific theories. (Pre-6, Spring 2001).

Table 2

Percentage of Participants with Desired Views of Targeted Nature of Science Aspects

NOS Aspect	Spring 2000 Explicit GCC Explicit NOS (*n* = 15)		FALL 2000 Implicit GCC Implicit NOS (*n* = 20)		Spring 2001 Implicit GCC Explicit NOS (*n* = 18)		FALL 2001 Explicit GCC Implicit NOS (*n* = 22)	
	Pre%	Post%	Pre%	Post%	Pre%	Post%	Pre%	Post%
Empirical nature of scientific knowledge	27	73	0	0	17	68	9	9
Tentative nature of scientific knowledge	0	60	0	5	6	56	5	9
Role of creativity	0	67	0	0	6	67	0	5
Subjective nature of scientific knowledge	20	80	0	5	17	67	32	23
Social & cultural influences	0	27	0	0	0	0	0	0
Observation vs. inference	27	67	0	0	6	56	14	14
Theories vs. law	0	80	0	0	0	78	0	0

The Tentative Nature of Scientific Knowledge

Consistent with the belief that a goal of scientists is to prove their ideas, participants viewed theories as weakly supported ideas that were easily and often revised. This misconception about the tentativeness of science as it related to scientific theories was common across semesters. In addition, participants consistently discussed scientific laws as aspects of scientific knowledge that were proven. Thus, the absolutist beliefs of the participants at the beginning of each semester were in contradiction to the common tenet in the scientific community of the tentativeness of scientific knowledge.

> Scientific theory has not stood the test of time or cannot be proven correct 100% of the time, such as the theory of evolution. Laws of science cannot be broken. (Pre-10, Spring 2001)

> A great example of [theory change] is the always-baffling unanswered question of how to lose weight. At least hundreds, if not thousands, of theories exist on this topic, many of which contradict one another and confuse the public. (Pre-2, Spring 2000)

The majority saw scientific laws as proven beyond a shadow of doubt. For these preservice teachers, scientific laws, along with facts and observations, constituted absolute knowledge that would never change. These participants also expressed the misconception of a hierarchical relationship between scientific theories and laws.

> A law is a theory that has been proven beyond a reasonable doubt. (Pre-22, Fall 2001)

> A scientific theory cannot necessarily be proven, whereas a law is believed to be a constant, accurate explanation of something in the science world that has been tested and re-tested. A theory is usually the first step in constructing, or formulating, a law. (Pre-9, Spring 2000)

Most participants linked the tentativeness of scientific theories to the empirical nature of science. In fact, the collection of new data and the accumulation of counter evidence were typically cited as the sole source of change. None of the participants mentioned the possibility that scientific theories could change due to new insight or new ways of looking at existing data.

The Role of Creativity in Constructing Scientific Knowledge

Although most participants expressed the belief that science involved creativity, particularly in "designing experiments" and to "create ideas to be tested", no one talked about the creativity of data interpretation. Several participants cited the "scientific method" as the regimen through which science progresses, a view that is at odds with science as a creative endeavor.

Prior to instruction, most of these preservice teachers viewed creativity as playing a role only before the real science (i.e., scientific method) is applied.

> Science and art are similar because in both genres you have to be creative and willing to experiment. Scientists have to create ideas to be tested while artists create how they want to portray an idea. Both fields follow methods, need materials, and experiment. (Pre-2, Spring 2001)
>
> Science has a method, but it is the scientists who expand this method, who work outside of the box, that are considered brilliant and ingenious scientists. (Pre-14, Spring 2000)

The Subjective Nature of Scientific Knowledge

The preservice teachers described a degree of subjectivity as inherent to the construction of scientific knowledge. Most participants spoke of subjectivity only in a general way, such as differences in "data interpretation": "There can be different interpretations of the data based on their knowledge." (Pre-22, Fall 2001). A few of the participants' pre-instructional responses described subjectivity in the negative sense that "…sometimes people 'see' simply what they want to believe" (Pre-6, Spring 2000).

Cultural Influences on Scientific Knowledge

None of the participants made any reference to cultural influences on the scientific enterprise in their pre-instructional responses to the questionnaire and follow-up interviews.

Post-Instruction Views of the Nature of Science

Substantial changes in participants' nature of science views were realized only in the post-instruction responses of the participants in the two explicit nature of science treatment groups (Table 2). In general, these responses reflected less commitment to absolute views of science and greater understandings of human factors contributing to the tentative nature of scientific knowledge. These results add further support to the growing body of literature supporting an explicit approach to the nature of science instruction (Akerson, Abd-El-Khalick, Lederman, 2000; Bell, Blair, Lederman, & Crawford, 1999; Shapiro, 1996).

The Empirical Nature of Scientific Knowledge

In the semesters that involved explicit instruction in the nature of science, the participants' post-instructional views differed in that a high percentage (73% and 68%) realized that scientists often go beyond the observable when constructing scientific ideas and theories.

> Different scientists look at the same topic in different lights drawing from their own theories, backgrounds, and research. While they have the same data, these factors lead them in different directions and approaches to the topic. (Post-12, Spring 2000)

> Every scientist comes to his work with a different set of experiences and pre-conceived notions. Just as two people can look at the same drawing/read the same poem and see/hear different things, so too can two scientists deduce different information. (Post-6, Spring 2001)

Whereas references to "proving" scientific ideas as "true" were common in the pre-instruction responses, the same ideas were largely absent from the post-instructional responses in the groups who received explicit instruction in nature of science. In the groups who received no explicit nature of science instruction, there was no change in the very small percentage of students who recognized the usefulness of various perspectives in the development of scientific knowledge.

The Tentative Nature of Scientific Knowledge

In the groups that received explicit nature of science instruction, post-instructional responses indicated important shifts in the participants' largely absolute views of scientific knowledge. While all participants continued to express the belief that theories change because of new evidence, several also described theory change as a result of new ways of looking at existing evidence.

> I think theories change….The theories about dinosaur extinction have changed because of new evidence and a new perspective on data. (Post-1, Spring 2000)

> Since theories are founded on interpretations of observations, different scientists may propose different theories despite potential use of the same set of data. (Post-11, Spring 2000)

All of the participants who received explicit nature of science instruction also spoke of the explanatory function of theories, something that was entirely lacking in their pre-instructional responses. In fact, in a majority of the post-instructional responses, participants contrasted theories and laws by their function, rather than level of "proof." Some referred specifically to nature of science activities in which they participated in their class.

> A scientific theory explains why something is happening. A scientific law is a summary of observations. It is a generalization ... it explains why something is happening. In the tube experiment, we made a law that said that no matter which string we pull, the longer one goes in. This is a summary of all our observations. (Post-18, Spring 2001)

> A scientific theory is an explanation of why something happens. A law is a summary of observations – it is a generalization about a phenomenon that is explained by a theory. (Post-2, Spring 2001)

Post-instructional responses in the two explicit nature of science groups also tended to contrast theories and laws by the types of knowledge from which they are derived. The participants clearly saw theories as inferential in nature and scientific laws as generalizations. This contrasted markedly with their pre-instruction misconception that laws are of the same type of knowledge and are, in fact, derived from theories.

In the two groups who received no explicit nature of science instruction there was no change in the responses about the tentativeness of science in the post-instruction data set.

The Role of Creativity in Science

In both semesters in which explicit nature of science instruction was employed, about 67% of the participants expressed adequate post-instructional views of the role of imagination and creativity in the generation of scientific knowledge. According to the participants in these two semesters of the course, creativity permeates the scientific process in both the design of experiments and in the interpretation of data. Most agreed that "creativity drives both scientists and artists" (Post-2, Spring 2000). The change in participants' views was further emphasized by their rejection of the conception of a single scientific method. Contrary to their prior beliefs, they allowed for many methods and creative approaches to the process of generating scientific knowledge.

> Not everything can follow the scientific method—like, if you're trying to find out about dinosaurs….I don't think that every time someone is going to state a hypothesis before they discover something. (Post-1, Spring 2000)

In the groups that received no explicit nature of science instruction, the percentage of students who expressed understanding of the creative processes in science was consistently negligible.

The Subjective Nature of Scientific Knowledge

The view that science is completely rational and objective was rejected by 80% and 67% of the participants in the explicit nature of science groups, in their responses to Item 5 of the posttest. Rather, they described how scientists' backgrounds, personal views, and biases toward the data potentially played a role in their interpretation of the data. Contrary to their pre-instructional responses, none of the participants cast subjectivity in a totally negative light.

> It is possible that different people make different inferences from the same data and observations. (Post-17, Spring 2001)

Different conclusions are the result of different interpretations of data. Scientists draw varying inferences based on unique personal experiences, backgrounds, and systems of thought and belief. Every individual is the product of a unique set of life experiences, program of study, and mindset. All of these factors affect how a researcher interprets a given set of data. (Post-11, Spring 2000)

Students who did not receive explicit nature of science instruction persisted in their general statements about why scientists might differ in their beliefs. None cited different interpretations of the data as a reason, and several continued to characterize differences in science as the result of personal bias and prejudice on the part of scientists. Even the group that received explicit GCC/GW instruction showed no gains in understanding the role of inference, interpretation, and theory development in science.

Cultural Influences on Scientific Knowledge

In contrast to the pre-instructional responses, in which the participants made no reference to cultural influences, 4 of the 15 participants (27%) in the group receiving BOTH nature of science and GCC/GW instruction described how cultural influences could affect the scientific enterprise and the knowledge it constructs. Three of these references to cultural influences described how the culture at large could affect what science is done and how it is received.

> [Without teaching theories] we would not see, for example, that the Copernican model that the earth revolved around the sun was widely unaccepted during his time because it rejected the Christian idea that the Earth is at the center of the universe and everything revolved around it. (Post-12, Spring 2000)

In the other three groups there was no gain in understanding the impact of the culture upon the scientific enterprise. This was the only aspect of NOS in which the second NOS group, the one which received no GCC/GW instruction, made no gains.

Global Climate Change/Global Warming

Pre-Instruction Views of Global Climate Change and the Nature of Science

In all semesters of the project, a large majority of the preservice teachers held pre-instruction misconceptions about GCC/GW. These included beliefs that the greenhouse effect is both unnatural and (always) harmful, that scientists as a group believe the same thing about GCC/GW, and that the greenhouse effect is either a scientific theory, because it is unproven, or a scientific law because it is proven.

In the pre-instruction questionnaires and interviews in all semesters, student responses ranged from statements about GCC/GW that contained multiple misconceptions to responses that used some correct descriptions and terminology. The ideas found in the following examples were commonly expressed in all semesters in the pre-instruction responses. Many students believed that the ozone hole was the primary causal factor in the greenhouse effect, that the greenhouse effect and global warming were synonymous, and that the greenhouse effect worked by trapping heat or gasses in the atmosphere.

> It [the greenhouse effect] is caused by a hole in the ozone layer which allows stronger sun rays in. The heat of the sun is slowly heating the temperature of the earth causing the polar caps to begin melting. This increases the amount of water in the ocean and leads to erosion on the shores and loss of land. (Pre-2, Spring 2000)

> The greenhouse effect is the gradual loss of the protective ozone layer due primarily to the release of certain man-made gasses. The loss of the filter is allowing more of the sun's rays to pass through the atmosphere causing a general warming of the Earth's surface. (Pre-2, Fall 2001)

In a few instances, students expressed correct understandings of the greenhouse effect and its mechanisms. Even these students expressed other misconceptions, such as characterizing the effect as a trapping of energy in the atmosphere, listing isotopes as greenhouse gases (C_{14}), naming gases that did not occur naturally prior to the 20th century (CFC's, first synthesized in

Table 3

Percentage of Participants with Desired Views of Targeted GCC/GW Aspects

Response Categories	Spring 2000 Explicit GCC Explicit NOS (*n* = 15)		FALL 2000 Implicit GCC Implicit NOS (*n* = 20)		Spring 2001 Implicit GCC Explicit NOS (*n* = 18)		FALL 2001 Explicit GCC Implicit NOS (*n* = 22)	
	Pre%	Post%	Pre%	Post%	Pre%	Post%	Pre%	Post%
Greenhouse effect (GE) is natural & mostly beneficial	26	67	15	30	6	6	5	73
Correct understanding of theory or law, connected with greenhouse effect	7	73	10	5	17	67	0	0
Scientists are characterized as individuals	40	73	35	45	22	50	27	27
Support for government energy policies	73	100	80	85	61	67	82	68
Informed conditional support for government energy policies.	0	67	5	5	0	0	0	5

1928), and failing to distinguish between particles and gases. Even the most correct descriptions were not correct to a level that one could reasonably expect any of the respondents to accurately teach the concepts to children. The following excerpts from student responses were the most correct pre-instruction responses from two class sets.

> Certain particles, CFCs, $C_{14,}$ and others form a blanket in the stratosphere that "insulates" the earth—keeps the earth warm by keeping heat emitted from the sun around the earth. (Pre-1, Spring 2000)

> Radiation from the sun enters into the earth's atmosphere and it is both absorbed by the earth and reflected by it. Part of the light and heat energy that is reflected gets trapped by the atmosphere and warms the earth.(Pre-15, Spring 2001)

Across semesters, participants' pre-instruction explanations about whether the greenhouse effect is a theory or a law reflected conventional understandings about theories as unproven conjecture and laws as proven. This was consistent across groups.

> If it were a law, it is probable that results/consequences of the phenomena would have to have been observed and recorded a number of times (it would become provable and a fixed phenomena). (Pre-9, Spring 2000).
>
> Theory. Since there is a difference of opinion on why the earth is warming, the greenhouse effect is only a theory. If someone could prove that the greenhouse effect explains the earth's warming 100% of the time, then it could be a law. (Pre-12, Fall 2000)

Another characteristic student belief was the uniformity of opinion about global warming in the scientific community. Most responses contained references to scientists as a single-minded group whose beliefs were expressed as one unit. This response corresponded to their pre-instruction beliefs about the subjectivity of science, and was consistent with their absolutist views of science.

> Scientists are certain that there is a hole in the ozone layer that continues to expand. Scientists are uncertain about the rate at which it is expanding, nor do scientists know for sure how grave the danger of increasing temperatures is. They only know that the Earth in general is warming up. (Pre-5, Spring 2001)
>
> Scientists are about 75% sure that the Earth is warming at a dangerous rate. They are trying to increase awareness about pollution and the depletion of the ozone to slow the warming of the Earth. (Pre-9, Fall 2001)

Consistent with the responses of the majority of the participants each semester that scientists were in agreement about global warming, over 60% each semester indicated willingness to support the development of alternative energy sources even if the actions taken raised their taxes or cost them in other ways. Pre-instruction data showed only one example in all semesters of application of knowledge of the nature of science and/or of GCC/GW in response to this question.

> Yes. I'm pretty convinced that emission reduction would perhaps slow down, if anything, this perceived effect. The problem is expense, of course, but I, personally, would support such a program. (Pre-10, Fall 2000)

The previous response contrasted with the prevalent sentiment expressed. Most students supported taxation for the proposed government program with reasoning that lacked critical consideration of the nature of science or the issue of global warming.

> Yes - anything to help save our Earth would be worth it. Eventually, they would hopefully be able to get the prices down. (Pre-18, Spring 2001)

> Yes!!! (Pre-17, Fall 2001)

Post-Instruction Views of Global Climate Change and the Nature of Science

As expected, only in the explicit GCC/GW groups did participants demonstrate substantial post-instruction gains in GCC/GW understandings. Though not every participant in the explicit GCC/GW groups moved to correct and complete understandings, a large portion of each class did (Table 3). Also, most participants were willing to support government action to encourage the use of alternative energy sources. The following sections highlight the changes in participant understandings of global climate change and the nature of science as it intersected with the study of global climate change.

At the end of the explicit GCC/GW semesters many more students held the correct understanding of the greenhouse effect, in contrast to very few at the beginning of the semester. The understandings expressed in their posttest questionnaires were generally more thorough and showed a deeper understanding of the processes involved in the greenhouse effect. Some respondents made a direct connection between the nature of models and the greenhouse effect as a model. Given that most participants were confused about the greenhouse effect at the beginning of the study, the thoroughness and clarity of posttest responses is especially notable.

> The greenhouse effect is a proposed explanation for increased Earth temperatures. It is not the same as "global warming," and often receives a negative connotation.

> The greenhouse effect is a model, much like a real greenhouse, that reflects gases held to the Earth by gravity that in turn insulates the earth's surface because of a loss of energy – we probably couldn't live on earth without some degree of greenhouse effect. (Post-9, Spring 2000)

> It is the net warming of the earth because some of the sun's energy is absorbed by the earth and then re-emitted and absorbed in the atmosphere. But some of the sun's energy escapes back into space. It does not cause "global warming," it is actually the phenomenon that allows the earth to be at this temperature. Otherwise temperatures would drop below 0°. (Post-20, Fall 2001).

Only in the explicit NOS instruction semesters did students' post-instruction responses indicate that a majority of the students understood that scientists are individuals and have various opinions about GCC/GW. In the semester where students received explicit instruction in both GCC/GW and NOS, 80% of the students in the class learned that scientists differ in their ideas about whether or not global warming is happening at a dangerous rate, as compared to 53% on the pretest. In the posttest responses, participants expressed an understanding of the function of inference in the development of scientists' ideas about global warming.

> Some scientists are certain that the Earth is warming at a dangerous rate. Some scientists are certain that the Earth is cooling, while others are certain it is all part of a cycle. They are all inferring different things based on the same data. (Post-4, Spring 2000)

In the other semester that included explicit NOS instruction, responses reflecting the individuality of scientists more than doubled in pre- to post- responses. For example, "I would say some scientists are certain while others aren't. " (Post-5, Spring 2001). Despite explicit reading assignments and meetings with research scientists, the explicit GCC/GW groups that did not receive explicit NOS instruction showed very little gain in understanding of the subjectivity of science as exemplified in the debate in the scientific community over global warming.

> I do not think they are very certain. They are just trying to follow the calculations that they have figured out. (Post-8, Fall 2001)

Prior to instruction, most participants in all semesters of the project based their choice of "theory" or "law" to characterize the greenhouse effect upon whether or not they believed the greenhouse effect was proven or not. Participation in the science methods course without NOS instruction did not result in gains in correct understandings of scientific theories and laws. GCC/GW instruction did not lead to gains in this area of nature of science understanding. In contrast, after instruction in the two explicit NOS semesters, about 70% of the participants responded to the question with correct explanations about theories and laws, and all 70% referred to the nature of the reasoning as the justification for their answer. Furthermore, they used the science process nomenclature of observation and inference, as they had been taught in the course, to clarify their reasoning.

> The greenhouse effect is a law—if it is described as the reflective effect of the atmospheric gases on radiant energy. If, however, it is described as being the effect of changes in atmospheric composition on global climate change, it is a theory. Laws are based on strict observations while theories are founded on inferences, which involve the interpretation of observations. (Post-11, Spring 2000)

> If it's based on observations – such as records of relative amounts of gas in a sample of the atmosphere – it's a law. If it's based on inferences – such as an explanation about why the Earth's temperature is rising – it's a theory. I think it's probably a theory because it's a possible explanation of why temperatures are rising. (Post-13, Spring 2001)

With the exception of one semester group, there was no notable change across semesters in the willingness to commit to paying for a government program to develop alternative energy courses. The group that received explicit NOS and GCC/GW instruction was the only group to show an overall shift to the use of explanations about their choices consistent with knowledge of NOS and GCC/GW (Table 3). In addition, this was the only semester in which many students explained their willingness in a manner that showed both their understanding of the GCC/GW issue and of the nature of science.

> If consensus within a majority of the scientific community were reached about the earth warming at a potentially detrimental rate, yes I would support the move to more costly alternative energy sources. (Post-1, Spring 2000.)

Even without GCC/GW instruction, the group receiving explicit NOS instruction developed better understandings of theories and laws and appeared able to apply these understandings to the topic of GCC/GW (Table 3). However, these participants' responses to the GCC/GW questions on the post-questionnaires showed no improvements in the application of the NOS topic to understandings of other NOS aspects, such as viewing scientists as individuals.

Discussion

Preservice elementary teachers in these groups made substantial gains in understandings of the NOS when instructed explicitly in aspects of NOS in conjunction with instruction in a controversial science issue, GCC/GW. These participants also made substantial gains in NOS with explicit NOS instruction and *no* instruction in GCC/GW. Explicit instruction in NOS appears to benefit student understandings of NOS whether or not it is combined with a controversial science topic, though the effect was greater when NOS and GCC/GW were both taught explicitly. Likewise, when no explicit instruction in NOS occurred, no gains were seen in NOS understandings.

Interestingly, most of the participants, all semesters, *believed* they had learned about the nature of science whether or not the topic was addressed explicitly in the methods course. This belief is contrary to the data for the implicit nature of science groups, whose understandings showed little change from pre- to posttest administrations of the questionnaire. However, given their responses to specific probing during the interviews, it appears that these preservice teachers conflated nature of science with science process skills, a topic that was addressed extensively in their methods course. This conflation has been reported in previous studies involving preservice teachers (Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 2000), and serves as a reminder that it is easy for methods students to confuse the method with the message, especially when an implicit approach is used.

The only gain in the explicit global climate change/implicit nature of science group was in the understandings about the definition of the greenhouse effect. Also, in the explicit NOS groups, gains were seen in the ability to connect the correct meaning of scientific laws and theories to the greenhouse effect, regardless of GCC/GW instruction. Therefore, it appears that in-depth, student-centered coverage of a controversial issue is not enough to improve participants' views of NOS. However, accompanying NOS instruction with investigations of a real-world topic that illustrates the NOS aspects and enables application of those aspects appears to be more beneficial than either approach alone.

The results of this investigation strongly support the necessity of an explicit approach to nature of science instruction (Bell, et al., 2000; Shapiro, 1996; Bell, Blair, Lederman, & Crawford, 1999). Instructional activities consistent with currently accepted ideas of NOS (e.g., footprints activity, science process skills activities, discussions of controversial topics) were employed in all iterations of this investigation, but were not enough. The specific aspects of the scientific enterprise that characterize the nature of science should be addressed specifically in instruction.

Although further research is needed before generalizing these results to other situations, this investigation provides support for an explicit, context-based approach to nature of science instruction in the elementary science methods course. While explicit nature of science instruction situated in the context of science controversy produced the greatest gains in nature of science understandings, explicit nature of science instruction alone was nearly as effective. Science methods instructors whose time constraints preclude including detailed instruction on science content or on a particular science controversy may see gains in their students' nature of science understandings through the less-time intensive explicit approach alone.

Future investigations will need to further assess nature of science instruction situated within and without science controversies (e.g., genetic manipulation, cloning, nuclear energy, and evolution) in order to explore the generalizability of the findings reported here. It is also important before generalization that other group situations be investigated; secondary or inservice teachers may respond differently to NOS instruction combined with GCC/GW. Also, it is important to extend this line of research longitudinally to address the critical question of whether elementary preservice teachers are able to translate their nature of science understandings into classroom instruction.

In the end of the semester interviews with participants who experienced explicit nature of science instruction, we asked whether this project would influence their future teaching. Their comments indicated intent to incorporate these understandings into their teaching, as illustrated in the following comment:

> [Studying GCC/GW and the nature of science] makes you realize that science isn't always exact and so you have a responsibility to teach both sides and all angles of a scientific issue. (Post-1, Spring 2000)

We believe the approach of explicit nature of science instruction has great potential for developing elementary teachers with complete understandings of the nature of science, and that adding in science content such as global climate change/global warming strengthens the understandings of the participants. Not only do the participants gain understanding, but science also becomes more accessible and relevant. As the participant quoted above remarked while packing up her bookbag after the interview:

> It makes me want to go back and re-evaluate what I thought I knew and ask more questions. Like, it kind of awakens the scientist inside me . . . (Post-1, Spring 2000)

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LEGISLATIVE CHALLENGES TO THE TEACHING OF EVOLUTION: THE SCIENCE EDUCATORS' RESPONSE

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The mandate to teach the theory of evolution and evolution-related concepts in biology and other appropriate science classes in public schools is relatively clear in thirty-one states and the District of Columbia. The remaining nineteen states receive a below average or failing grade in the teaching of evolution and evolution-related ideas (Lerner, 2000). In the most recent state legislative sessions (e. g. Arkansas, Michigan, Louisiana, and Pennsylvania), some legislators made attempts to use the legislative processes to restrict the teaching of evolution or mandate teaching of non-scientific explanations for the origin of species and the universe.

On June 20, 2001 the American Geological Institute Government Affairs Program reported on its website (http://www.agiweb.org/gag/legis107/evolution_update0601.html) that the United States Senate became involved in the evolution controversy. A Sense of the Senate amendment was passed 91-8 as an amendment to Education Bill S.1. This amendment stated:

> It is the sense of the Senate that—(1) good science education should prepare students to distinguish the data or testable theories of science from philosophical or religious claims that are made in the name of science; and (2) where biological evolution is taught, the curriculum should help students understand why this subject generates so much continuing controversy, and should prepare the students to be informed participants in public discussions regarding the subject.

The language of this resolution significantly changed in the education bill that was reported out of the House-Senate conference committee and subsequently passed by both houses.

The states' efforts and the tactics used in the United States Congress impact our lives as science educators. What are these impacts and what are some possible responses? The following two case studies represent the attempts by legislators in Arkansas and Michigan to restrict the teaching of evolution.

Arkansas House Bill 2548 (2001): Déjà vu All Over Again

Chronology of Events

On March 5, 2001 the legislative sponsor introduced House Bill (HB) 2548 in the Arkansas General Assembly and the bill was referred to the State Agencies and Governmental Affairs Committee. The title of HB 2548 was:

> An Act to Prohibit State Agencies and Other Public Entities from Using Tax Dollars to Purchase or Distribute Material that They Know or Should Have Known Contains, or Presents as Factual, Information which Has Been Proven False or Fraudulent; and for Other Purposes.

Referring this bill to the State Agencies and Governmental Affairs Committee instead of the Education Committee was the first of many unusual events. The chief reason for this referral was that the chair of the committee was the author of the bill. He wanted the bill reported with a due pass recommendation by the committee to the Arkansas House of Representatives.

On March 19 HB 2548 was amended to its current form and was posted on the legislative web site (www.arkleg.state.ar.us/ftproot/bills/2001/htm/HB2548.pdf). The bill required first, specified state agencies, including public schools, not to use public funds to purchase materials which contain false evidence. Second, the information is to be as accurate as possible and, third, during instruction, when any material is deemed false according to the bill, the instructor will direct students to make marginal notes that the statement is false. Finally, during instruction the teacher will direct students to make marginal notations when any statement is identified as a theory.

The bill continued by naming seven theories but stated that the concern with theory should not be limited to these particular named theories: age of the earth, origin of life, homology in vertebrate limbs as evidence for common ancestry, geologic column accurately representing different time periods on earth, fossils representing missing links between life forms, and carbon/radioisotope and potassium argon dating. The next section of the bill defined science as:

> A special way of knowing and understanding the physical world that uses the "scientific method" to conduct rigorous investigations into processes that are observable and repeatable. . . employs skeptical peer review and experiments attempting to falsify ongoing and prior scientific work to ensure the validity and integrity of results. (HB 2548, 2001, p. 2).

Finally, the bill enumerated a list of what it labeled as false or fraudulent science but did not limit the bill to these instances. The false/fraudulent science list included: Haeckel's embryos; Miller-Urey experiment; archaeopteryx as a missing link; peppered moths; fossil horses; Heidelberg, Nebraska, Piltdown, Neanderthal, and Cro-Magnon man; Homo-erectus made from a few scraps of bone found in 1891; Lucy; vestigial structures; and lobe-finned fish.

The author of the bill admitted that much of the information in the bill came from Jonathan Wells (2000), *Icons of Evolution*. On March 19 e-mails from the Evolution Education Arkansas listserve (Evoledar-l@l2.uca.edu) provided constant updates and advice from the National Center for Science Education (www.ncseweb.org). Ironically, Monday, March 19 was the first day of spring break for most colleges and universities in Arkansas. Despite this, members of the Evoledar and the Evolution Group at the University of Arkansas (U of A) alerted the U of A academic community that this bill was in committee. Members of these groups immediately wrote e-mails to the House committee members expressing their concerns.

On Tuesday the committee heard the bill. There were two speakers opposed to the bill and a number of people who spoke in favor of the bill. The executive director of the Arkansas Civil Liberties Union and a geologist in the Department of Chemistry and Physics at Arkansas State University spoke against HB 2548. The sponsors of the bill invited Kent Hovind from Florida to speak as an expert witness for the bill. Mr. Hovind is a creationist minister who has graduate degrees in Christian education from Patriot University. After Mr. Hovind's testimony the bill passed with one dissenting vote and was sent to the House. This action prompted additional e-mails to committee members explaining the numerous problems with the bill.

I received a response from one committee member to my comments about the nature of science. "To me science is fact. Theory has not been proven. Evolution is theory." In addition I wrote to the University of Arkansas' Provost alerting him to the possible effects HB 2548 could have on the university at large and the library in particular.

On Wednesday the House scheduled the bill for consideration, but the bill ran into procedural difficulties for lack of a financial impact statement. The sponsor of the bill asked that the rules be suspended and received a 47-44 vote against suspension.

The House considered the bill again on Thursday. By this time a number of the most active science teachers in the state of Arkansas were in St. Louis for the National Science Teachers Association (NSTA) Annual Convention, where, ironically, I (Wavering, 2001(a)) was presenting a paper titled, "Why is Evolution a Dirty Word?" Meanwhile, a spirited floor debate occurred in the Arkansas House. One of the legislators was quoted as saying, "This law is clearly unconstitutional. Folks, if we pass this, we will not be shooting ourselves in the foot; we'll be shooting our foot off" (Fulton, 2001, April 14, e-mail communication). When the vote was taken, 45 voted yes, 36 no, and 19 either didn't vote or voted present. In the Arkansas

Legislature 51 votes are needed for passage; consequently, the measure failed. The sponsor wasn't sure whether he would bring it up again in the legislative session with only three weeks remaining.

Even though the legislative action had ceased for a short time, e-mails to legislators continued from the opponents and proponents of HB 2548. Editorials and letters to the editor became a daily affair in the newspapers. Between March 23 and June 4 more than 40 letters and editorials appeared in the *Northwest Arkansas Times* and the statewide *Arkansas Democrat-Gazette*.

During this time I wrote e-mails to all the members of the Arkansas House who voted against, present, or didn't vote for HB 2548 thanking them for not supporting the bill and providing them with more information about the problems with the bill. Members of the Evoledar and U of A Evolution groups provided members with information on sources for the bill and information about the particular charges made by the bill with regard to false or fraudulent science. I received e-mail messages from three members of the legislature thanking me for my e-mails. Apparently, the legislators were receiving many messages criticizing them for their votes and were grateful to receive some encouragement for a vote that might be controversial with their constituents.

The science curriculum specialist at the Arkansas State Department of Education played a key informational role while HB 2548 was moving through the legislative process. During this week he asked me to contact a local legislator who wanted more information about the problems with the bill. Her e-mail thanking me for the information included the following, "Although the 'educated' community has applauded my vote, I have had some people berate me as tho(ugh) I am some type of atheist" (Borhauer, 2001, March 27, e-mail communication). Further, I wrote the director and associate director of the Arkansas Department of Education briefing them on the faults of HB 2548.

When the Kansas problem with evolution occurred a year and half earlier, I wrote a guest editorial concerning the impact of that action on the state of Arkansas (Wavering, 1999). An editor at the *Arkansas Democrat-Gazette* was receptive to me writing another a guest editorial this time about HB 2548. It was published on Monday, April 2 (Wavering, 2001(b)) and was titled, "It's Just a Theory" (see Appendix A). The editorial stated my opposition to HB 2548 was based on its distortion of science and use of the word theory and that NSTA had a good definition of the nature of science at its website (http://www.nsta.org/handbook/natureofscience.asp).

On April 3 a motion to expunge the vote of March 23 failed, but on April 12 the Arkansas House voted to expunge the vote on which HB2548 failed to pass. This vote was 70 yes, 5 no, 4 present, and 21 not voting. On April 7, I wrote the executive director of the Arkansas Science Teachers Association (ASTA) encouraging the organization to develop a position statement that would help the organization respond to the challenges provided by HB 2548. Board members of the ASTA had written letters to the legislators and the state department of education but had not been able to respond in a timely fashion as an organization, due to the lack of policy statements. The e-mail message outlined a three-prong statement about the nature of science, the teaching of evolution, and the relationship between science and religion.

This resulted in a Position Statement on Science Education which has been added to the ASTA website (www.aristotle.net/~asta/science.htm). After the vote to expunge the March 23rd vote, the letters to the editors of the state's newspapers continued for almost two more months. Two of the last letters included an interesting exchange. A thirteen year old middle school girl wrote to say she was choosing evolution as a scientific theory ". . . backed up by a lot of evidence. It is not just something that someone dreamed up." The reply to this young woman was that she was courageous but wrong. The House postponed reconsideration of the bill indefinitely and referred it to the Education Committee for the interim during the legislative sessions, which is where it currently remains.

Michigan House Bills 4382 & 4705 (2001): The Evolution of Anti-Evolution Legislation

Chronology of Events

On February 28, 2001 House Bill 4382 was introduced by Representatives Gosselin, Garcia, Vander Veen, Bradstreet, Vear, Kooiman, Hager, Voorhees, Kuipers and Tabor and referred to the Committee on Education (of which co-sponsor Kuipers is committee chair). The bill was entitled, "A bill to amend 1976 PA 451 entitled ‘the revised school code.’" (http://www.michiganlegislature.org/txt/house.bills.intro/2001-2002/4382hhhh.htm). The bulk of the bill's text is primarily tweaked technical language in the school code. The last four paragraphs of the six-page bill address the teaching of evolution. That section of the bill is shown below in Figure 1.

Prior to this proposed legislation, the controversy had reared its head in myriad ways around the state. Katy Duggan-Haas (Don's wife) worked in science teacher professional development and knew biology teachers in the area who did not teach (or accept evolution). The former president of the school board in the district in which Don lived had written an op-ed piece on how creationism and evolution should both be taught in public schools. The Michigan Scientific Evolution Education Initiative (MSEEI) had been established to help teachers to better teach evolution and to deal with the political issues surrounding the teaching of evolution.

MSEEI is intended to provide an ongoing support system for teachers. MSEEI has an extensive and user-friendly web site: http://web.grcc.cc.mi.us/mseei/.

I became aware of the legislation on March 7, when Kalamazoo College biologist Paul Olexia forwarded me an email regarding the legislation (I was then teaching at Kalamazoo College). He received the information from a former student who now works at the National Center for Science Education. I sent an email with the key text from the bill and a query about how academics should respond to science educators and scientists I knew around the state. Simultaneously, others were sending similar emails to their colleagues and these informal networks eventually overlapped and became somewhat more formalized.

Relevant text from the Michigan HB 4382 follows:

> 10) As soon as practicable after the effective date of this subsection, the state board shall revise the recommended model core academic curriculum content standards under subsection as follows:
> In the science standards, all references to "evolution" and "how species change through time" shall be modified to indicate that this is an unproven theory by adding the phrase "all students will explain the competing theories of evolution and natural selection based on random mutation and the theory that life is the result of purposeful, intelligent design of a creator."
> In the science standards for middle and high school, all references to "evolution" and "natural selection" shall be modified to indicate that these are unproven theories by adding the phrase "describe how life may be the result of the purposeful, intelligent design of a creator."
> In the science standards for middle and high school, all references to "evolution" and "natural selection" shall be modified to indicate that these are unproven theories by adding the phrase "explain the competing theories of evolution and natural selection based on random mutation and the theory that life is the result of the purposeful, intelligent design of a creator."

I also sent a more targeted email to a collection of scientists from Kalamazoo and Michigan State (where I had done my graduate work). This second email proposed that a collection of scientists and science educators from the two institutions co-author an op-ed piece for newspapers around the state, especially those papers in the western more conservative area of the state. The group initially included myself, two biologists from Kalamazoo College, and an astronomer, and a geologist from Michigan State. Some members of the group had been contacted by the media already in reference to the bill and had been quoted in newspaper stories or on Michigan Radio (the NPR network covering much of the state based at the University of Michigan).

The media coverage allowed interested others to contact us. This led to a larger group of co-authors from a larger group of institutions, including two Christian colleges. When the op-ed piece was sent to papers, it had authors from a large public university, a small secular liberal arts institution and two conservative Christian colleges. The fields represented by the nine authors included science education, astronomy, geology, environmental science and, of course, biology. The letter is included in Appendix B.

The authors of the piece are omitted here as one of the biologists from one of the Christian institutions was called before his institution's president had received complaints from a board member about the piece appearing in the local paper. He notes the problem was more because the president did not know the letter had been sent and was therefore blindsided by the board member rather than the content of the letter per se. While he will continue to write to representatives, he is hesitant to write about the subject for publication.

The diversity of academic affiliations for the authors was intentional. With my background in Earth science, I sometimes see the creationist attacks almost exclusively on biology as a relief but more generally I see it as another red flag signaling for more public education. While the issues surrounding creationism, intelligent design and evolution may have their political center in high school biology, the issues are clearly relevant in the Earth sciences and astronomy as well. Also whether public or private, sectarian or secular, the overwhelming majority of scientists accept evolution as a robust scientific theory.

The letter was published in at least four papers in the state. None of them listed the full raft of nine authors and calls to some papers who had not initially published the letter led to a lesson. Two papers had not published the piece because of unclear local connections. The order of authors was initially to be alphabetical, but the first alphabetical name was a latecomer to the writing effort and he did not feel it appropriate that he be listed first. Consequently I was listed first followed by the others in alphabetical order. In future such efforts, we will list the authors from local institutions or who live in the newspaper's delivery area first. Phone calls did clarify this, but it would have been quicker to list the authors in different orders for the different papers. Not every paper was called and the piece did not run in all nine papers to which it was submitted.

The publication dates ran from a few days after its April 11 submission (it appeared on April 14 in the Holland Sentinel) to a month after submission in the Jackson Citizen Patriot on May 11. The delay here was due to unclear local connections clarified by a phone call.

From early on, Greg Forbes, the director of MSEEI, maintained regular contact with John Hansen, the minority Vice Chair of the House Education Committee. Hansen was opposed to the legislation. Several others had some contact with Hansen and with sponsors of the legislation. Hansen raised the point that the majority of introduced legislation never gets a hearing and he suspected that would be the case with this as well.

I had also been in contact with Rep. Hansen and a few members of the clergy. Hansen requested names of Christians who would be credible to the sponsors of the legislation and opposed to that legislation should a hearing be called. I did not fit this description well, but knew some who did.

Forbes also wrote "Dorothy and Toto Visit Michigan: Anti-Evolution Education Bill (HB4382) Introduced in House of Representatives" for the Michigan Science Teachers' Association Newsletter about the bill. The article ran in the April/May newsletter and is available online at http://www.msta-mich.org/publications/newsletter/newsletter.april may01/ dorothy.html.

Throughout this time, the electronic discussions going on around the state had become more formalized through the formation of Michigan Citizens for Science (MCFS), adapting from a similarly named group that had formed in Kansas. The group established a list serve and a web site (http://mcfs.netfirms.com/) and those in the Lansing area met periodically.

On May 3, 2001, a new bill was introduced by Reps. Gosselin, Bradstreet, Vander Veen, Voorhees, Vear, Hart, DeWeese, Julian, Kooiman and Drolet and referred to the Committee on Education. The complete text of that much shorter bill, Michigan HB 4705, is listed below. At this writing, January 2002, neither bill has had a hearing and it does not appear likely that either will.

> A bill to amend 1976 PA 451, entitled "The revised school code," (MCL 380.1 to 380.1852) by adding section 1164.
> The people of the state of Michigan enact:
> SEC. 1164. The teaching in a public school science class or the methodological naturalism hypothesis as an explanation for the origin and diversity of life shall not preclude also teaching the design hypothesis as an explanation for the origin and diversity of life. A public school official shall not censor or prohibit the teaching of the design hypothesis.
> As used in this section:
> "Design hypothesis" means the theory that life and its diversity result from a combination of chance, necessity, and design.

> "Methodological naturalism hypothesis" means the theory that nature is all there is and that all phenomena, including living systems, result only from chance and necessity.

The op-ed piece led to Kalamazoo College biology professor, Jim Langeland, and my appearance on a call in radio talk show. We were guests on WKMI AM Kalamazoo's Marci & Company on May 14, 2001. We only agreed to be on the show after clarifying that we would not be debating anyone in the studio, just speaking our piece and taking calls. The calls came in at a high enough volume to add an additional half hour to our scheduled hour. Most of the callers seemed to hold a literal biblical interpretation of creation (as opposed to the intelligent design position of the legislation). Unfortunately, the engineer was ill the day of the show and it was not recorded.

As a result of my name being connected with the op-ed piece, appearing on the radio and being quoted in other press sources, I have received several emails and letters. There were fewer than ten in all, and the majority came in response to the radio appearance. These responses included claims that I was harshly anti-Christian and a claim that I was not anti-Christian enough. Most common in the responses was an invitation to come to evangelical church services. None of the correspondence indicated that my involvement led to deeper understanding of the issues.

There has been no legislative action on either Michigan bill, but they have generated media coverage around the issues of creationism, intelligent design and evolution. The fact that such legislation is written (let alone brought to a vote) is a clear signal that science education has not been as effective as it should be. It is also a clarion call for public education on these issues.

Questions for Consideration

These legislative initiatives represent both a failure of science education and an opportunity for science educators. The panelists for this paper set presented case studies of efforts by legislators in the states of Arkansas (Arkansas House Bill 2548) and Michigan (Michigan House Bills 4382 & 4705) to significantly weaken the teaching of evolution in these states.

The following questions are presented for discussion. What is the responsibility of the science educator for political action? What are effective measures in taking political action? What actions are counterproductive? What are short range and long range actions? What does the frequent recurrence of these issues tell us about the contexts from which students are coming? How should that inform our teaching of future science teachers? Who are allies in this effort? What are the costs and benefits of such actions? How can we form alliances that respond to these initiatives? Should we take a more active role in the education of the public about evolution and the nature of science? What other questions do these cases suggest?

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Appendix A

Guest Editorial to the Arkansas Democrat-Gazette, April 2, 2002

It's Just A Theory

By Michael Wavering

The debate about the bill to remove fraudulent and false information from the public schools' science curricula concerns the nature of a theory. House Bill 2548 would require that "when any statement in instructional material is identified by the instructor to be a theory, the instructor shall instruct the class to make a marginal notation that the statement is a theory."

Later in the bill, the authors define science as "a special way of knowing and understanding the physical world that uses the scientific method to conduct rigorous investigations into processes that are observable and repeatable." They also call it "a discipline that employs skeptical peer review and experiments attempting to falsify ongoing and prior scientific work to ensure the validity and integrity of results." The bill's definition of science does not, however, acknowledge the role that theory plays in science.

Theory has many meanings. In everyday usage the word theory means a guess or speculation. We all have watched television programs in which the detective makes a statement about his theory of who committed the crime.

In science, theory works differently. A scientific theory is an explanation of a set of events or observations that is well supported by previous observations and experiments. Many theories are so well supported that scientists no longer debate them, but instead do experiments and make observations to refine the details of the theory.

The major function of science is to develop these theories, or explanations. As a result, theoretical knowledge forms the basis of science. Evolution is a theory, but so are atomic theory, plate tectonic theory, cell theory, gene theory and gravitational theory, to name just a few.

House Bill 2548 names a set of theories, which are all tied to the theory of evolution, but additionally states that the bill should "not be limited" to those theories mentioned. So in essence all of scientific theory is called into question by the bill.

While it is true that theories cannot be proven, because scientists cannot observe every instance of a phenomenon, scientific theories represent the best explanation currently available.

This points to the provisional nature of scientific knowledge, in that science undergoes revision as new observations and theories are developed. The theories mentioned above and many others have undergone the rigorous intellectual scrutiny of scientists over many years and provide the best current explanations of the natural world.

House Bill 2548 represents a misunderstanding of the nature of science. For a good statement of the nature of science, I refer readers to the National Science Teachers Association web site, where there is a position statement on the nature of science. See http://www.nsta.org/handbook/natureofscience.asp.

The Arkansas Legislature should not get into the business of defining science when there are appropriate organizations that have already done so. I sent an e-mail message to this effect to the House committee before the bill came before the full House. One of the members responded: "To me science is fact. Theory has not been proven. Evolution is theory."

However, the National Science Teachers Association, in its position statement on the nature of science, states, "A primary goal of science is the formation of theories . . ."

Science is more than facts; it is based on the best current explanations, or theories, which in turn are based on a vast body of research. Theories cannot be proven. Evolution is a theory, as are all the explanations that scientists propose. It isn't "just a theory" or "only a theory," but scientific theory.

That is why, if House Bill 2548 should pass, I fear that it would make our state look ignorant and backward in the eyes of the world.

Appendix B

Michigan Op-Ed in Response to HB 4382:

April 11 2001

To the Editor:

We are writing as individual faculty members from departments of biology, geology, astronomy, and science education from several Michigan colleges and universities. We are concerned about recently proposed legislation in the Michigan House (HB4382) to change the state's science education standards to include the teaching of "intelligent design" as an alternative to evolutionary theory, and the characterization of scientific theories as "unproven."

The language of the proposed legislation refers to evolution as an "unproved theory," but this phrase is misguided for two reasons. First, evolution is a demonstrable fact--species have changed dramatically over geologic time and continue to change today. There is simply no debate about this among scientists. Secondly, evolution also has a theoretical context but the phrase "unproved theory" suggests a misunderstanding of what constitutes a scientific theory on the part of the framers of the bill. The term "theory" has a very precise meaning in the scientific community; it refers to a possible explanation (hypothesis) of the cause of observed facts that has been subjected to numerous tests. Only after an hypothesis has been successfully tested, that is, subjected to attempts to disprove it and passed--can it be elevated to the status of theory. Scientific theories are continually tested as new data and new interpretations come to light or as advances in technology provide new ways to test them.

Thus a scientific theory has been rigorously and repeatedly tested and has proved to be true as far as our current understanding allows. Scientists avoid the word "proven" because of the nature of science itself. In a sense, no scientific theory is ever proven once and for all, because our knowledge base-the raw material for testing theories-is continually expanding. Scientific theories achieve their stature by successfully explaining natural phenomena. Countless long-cherished theories (for example, the pre-Galilean concept of an Earth-centered universe) have been relegated to the "dustbin of science," replaced by new, improved versions. As a result, scientific understanding of how the world works is constantly changing. Change is the hallmark of scientific inquiry. Current evolutionary theory successfully explains countless observations that demonstrate how life has changed over billions of years of Earth history and is continually being modified as new observations and data arise. It clearly ranks among the most robust of all theories in science.

In contrast, the concept of Intelligent Design, the belief that "life is the result of the purposeful, intelligent design of a creator," is written in stone. There are no pesky details with which to quibble, no questions left unanswered--the presence of an "intelligent designer" explains all. There is no opportunity for this explanation to change based on new data, new technology, new interpretations. It cannot be tested; by its very nature it is not amenable to disproof, correction or improvement. The concept of the intelligent designer, then, is not scientific; it cannot be regarded as a viable hypothesis or theory, and therefore does not belong in our state's science curriculum.

We think it is important for our youth to have an appropriate understanding of the issues that fall within the realm of science and those which do not. The proposed legislation confuses science with non-science and does a grave disservice to all the citizens of Michigan.

IMPLICATIONS OF DIVERSE MEANINGS FOR ‘SCIENTIFIC LITERACY’

Andrew C. Kemp, University of Louisville

Introduction

Many science educators in the United States currently promote the goal of “scientific literacy” as the central organizing theme of their discipline (AAAS, 1993; Bybee, 1997; NRC, 1996). However, the goal of scientific literacy is not without its critics. One of the main issues concerns the meaning of the term ‘scientific literacy.’ As Shamos (1995) puts it, “there is no consensus on what ‘scientific literacy’ means or should mean. Instead, everyone involved with science education appears to have a vague, ill-defined notion of what it should mean” (Shamos, 1995, p. 160). Many others have also commented that scientific literacy lacks a clear definition or has too many of them to be useful (Agin, 1974; Champagne and Lovitts, 1989; Hurd, 1969; Kyle, 1995; Roberts, 1983; DeBoer, 2000). Along similar lines, the rationales given to promote the goal of scientific literacy have also been criticized. For example, Atkin and Helms (1993) claim that rationales for scientific literacy have accumulated over time, but they are rarely critically examined to see if they are mutually compatible or desirable. Shamos (1995) asserts that claims to support the goal of scientific literacy lack legitimacy. He says there is little or no evidence that scientific literacy is required for individuals “to be successful in most enterprises or to lead the ‘good life’ generally” (Shamos, 1995, p. 98). Thus, in spite of the hundreds of publications concerning scientific literacy, Laugksch (2000) concludes that at the beginning of the 21st century there is still “a view that scientific literacy is an ill-defined and diffuse concept” (p. 71).

This paper reports some of the findings and explores the implications of a study undertaken to examine the views of 9 university science educators on the meanings of the concept of 'scientific literacy' (Kemp, 2002). The participants of this study have diverse views on what constitutes 'scientific literacy,' but in general their views seem to fall into three categories, which I label as follows:

- Personal Scientific Literacy
- Practical Scientific Literacy
- Formal Scientific Literacy

The main goal of this paper is to explore some of the implications of these three views for policy, programs, and practices in science education, and to make recommendations for future research and work related to scientific literacy.

Significance

If 'scientific literacy' has a number of meanings, science educators may believe they are all working toward the same goal when, in fact, they are pursuing different ends. Any differences in meanings that exist for 'scientific literacy' could have serious repercussions for science education in general.

Purpose of the Study

This study critically examines the contemporary meanings attributed to the term 'scientific literacy' among participants sampled from one group of stakeholders, namely, university science teacher educators. I attempt to discern whether or not this diversity is (or is perceived to be) hindering efforts to improve the teaching and learning of science in the U.S.

Theoretical Underpinnings

The perspectives informing this study include the historical literature on reform in science education since World War II (e.g., DeBoer, 1991), the literature on scientific literacy (e.g., Bybee, 1997, Laugksch, 2000; Roberts, 1983), and the interpretive research tradition in science education (Erickson, 1986; Gallagher, 1991). I use constant comparative analysis (following Strauss and Corbin, 1990) to identify the categories, properties, and dimensions of views on the concept of 'scientific literacy.'

Design And Procedures

The main source of data for this study consisted of interviews with 9 university science teacher educators who were identified (by self or others) as being "knowledgeable" about the subject of scientific literacy (see Table 1). The first five participants were selected for this study because they were invited delegates to an international symposium concerned with scientific literacy, and thus were clearly regarded as knowledgeable about the topic by other science educators. One participant was encountered fortuitously at an educational conference, and 3 others recommended by one or more of those previously interviewed. Several other people were considered for interviews, but time and money limited my ability to gain face-to-face access to them. I considered 9 participants sufficient for this study because little new or relevant data seem to be emerging from the latter interviews, and I believed the emerging categories were becoming "theoretically saturated" (Strauss and Corbin, 1990, p. 188). Theoretical saturation is a necessary condition of conceptual adequacy for a grounded theory (Strauss and Corbin, 1990). However, it is important to note that as with any study involving a small sample size, I do not intend for the results here to be construed as fully representative of the science education community as a whole. Any hypotheses I put forth here should be viewed as tentative and limited in scope.

Table 1

Participant Pseudonyms and Characteristics

Pseudonym	Gender	Primary Activities Related to Scientific Literacy
Dr. Andrews	Male	Science education professor, large university
Dr. Benjamin	Male	Science education professor, small university
Dr. Curtis	Male	Science education professor , mid-sized university
Dr. Dobson	Male	Science education professor, large university
Dr. Gilbert	Female	Science education professor, large university
Dr. Howard	Male	Science education professor, large university
Dr. Infeld	Female	Science education professor, large university
Dr. Johnson	Male	Science and science education professor, large university
Dr. Kellogg	Female	Science education professor, mid-sized university

Note. The participants are listed in the order they entered the study. The researcher assigned pseudonyms and they have no particular significance.

I interviewed each participant in person. In some cases, a second personal interview or written interview was conducted to clarify and extend their responses. The interviews were semi-open ended, and consisted mainly of indirect questions so that I could compare the internal consistency of their responses. For example, I asked them to describe a scientifically literate person they know; to tell why they considered themselves scientifically literate; and to decide whether or not they would consider Einstein to be scientifically literate today if he were to be resurrected somehow. Following the constant comparative method (Strauss and Corbin, 1990), I analyzed the data in a series of coding cycles in an attempt to inductively derive themes about science educators' views of the goal of science literacy. More information on the methods employed in the study, as well as more detailed findings and discussions, may be found in my dissertation (Kemp, 2002).

Findings and Narrative Model of Participants' Views on Scientific Literacy

Scientific literacy is a complex goal that currently serves as the foundation for much of school science education in the United States. Participants' conceptions of 'scientific literacy' include a number of elements (i.e., attributes of the scientifically literate), as well as several supporting rationales. In the two sections that follow, I will first describe some commonalities in the views of the participants. Next I will discuss points on which the participants have diverse and even contradictory views.

Points on which Participants Agree

All the participants agree that scientific literacy is the most important goal for science education. They view the concept of scientific literacy as being relatively complex. For example, they all include a multitude of desirable or necessary attributes for the scientifically literate person to possess (Figure 1). The fewest number of important attributes, or 'elements,' of scientific literacy that I coded for any of my participants is 9, and the most is 22. While the participants did cover a wide array of elements, they did not include the entire universe of possible attributes (e.g., 'knowing connections between science and art,' 'using science for entertaining guests,' etc.). In some cases, elements are most likely not included because they are not considered important, but in other cases all might agree that a characteristic should be

Conceptual Dimension of Scientific Literacy

The scientifically literate person knows and understands:

- science concepts
- the physical world
- science vocabulary
- broad principles of science
- scientific inquiry
- relationships of science to mathematics
- limitations of science and technology
- the tentativeness of scientific/technological knowledge
- science is a social activity
- science and technology are human endeavors
- the history of science
- relationships between science and society
- relationships of science to technology
- relationships between science, technology, and society

Procedural Dimension of Scientific Literacy

The scientifically literate person is able to obtain and use information:

- self-learn science
- use science in everyday life
- apply science for social purposes
- decode science communications
- encode science communications
- think scientifically
- reason and argue
- judge validity of claims
- make decisions
- solve problems
- integrate knowledge
- engage in inquiry
- *use some of the tools of science*

Affective Dimension of Scientific Literacy

The scientifically literate person has a/an:

- appreciation for science
- interest in science
- inclination to stay up to date
- inclination to monitor and act on science-
- related social issues
- objective, open mind and skepticism
- ethical values
- self-confidence to use science
- appreciation of the world

Figure 1. A composite outline view of elements of scientific literacy grouped by dimension.

excluded as a part of scientific literacy. For example, it is doubtful that any of the participants would say the scientifically literate should "hate science." So, while there are a number of elements of scientific literacy, the range of elements is apparently not limitless.

All the elements of scientific literacy espoused by my participants can be classified into three Dimensions, which I call the Conceptual, Procedural, and Affective Dimensions. The Conceptual Dimension includes those things that can be classified as knowledge or understandings necessary for scientific literacy. The most commonly discussed Conceptual elements include 'knowing science concepts,' and 'understanding the relationships between science and society.' The Procedural Dimension covers procedures, processes, skills, and abilities that the participants think are attributes of the scientifically literate. Procedural elements frequently mentioned by participants include the abilities to 'acquire information,' 'use science in everyday life,' 'use science for social/civic purposes,' and 'decode science communications.' The Affective Dimension comprises a range of attributes connected to emotions, such as feelings, attitudes, values, and dispositions associated with scientific literacy. 'Appreciation for science' and 'Interest in science' are the most often cited Affective elements for scientific literacy, though individually they were not as frequently endorsed as the other common elements described above.

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Each of the participants seems to put much of their emphasis on only one or two Dimensions (and on only a few elements within each Dimension). Nevertheless, all of them support at least one element in each of the three Dimensions of scientific literacy views, thus I do not mean to convey the impression that they consider any of the Dimensions unimportant. Additionally, while the three Dimensions are fixtures, the participants recognize the emphasis placed on them by science educators might increase or decrease over time. A good example is the 'conceptual knowledge' Dimension, which several participants believe is less important now than a few decades ago.

The most commonly supported elements (Figure 2) might be thought of a 'core' of scientific literacy. However, these "common" elements actually mask a fair amount of diversity in participant views about content and emphasis. For example, while participants agree that knowing some science concepts is an important element of scientific literacy, they do not necessarily agree about exactly what science concepts need to be learned, and to what extent or depth they should be understood. Still, these commonly endorsed elements could be seen as features requisite to all programs that intend to promote scientific literacy.

Conceptual Dimension

The scientifically literate person has some knowledge and understanding of
- Science concepts
- Relationships of science and society

Procedural Dimension

The scientifically literate individual is able to
- Obtain and use information
- Apply science in everyday life
- Use science for social and civic purposes
- Understand science-related communications in the public media

Affective Dimension

The scientifically literate individual has
- An appreciation for science
- Interest in science

Figure 2. Outline of the most commonly endorsed elements of scientific literacy.

To a significant extent, the elements emphasized (or excluded) by participants are linked to the rationales they endorse for the goal of scientific literacy. In other words, the reasons why participants think scientific literacy is necessary or desirable significantly influences which attributes they say are required to be scientifically literate. The rationales for scientific literacy espoused by my participants can be classified into four Domains, which result from the intersection of the scale (personal or group) and utility (practical or abstract) foci of the rationales. The four rationale Domains include: Practical Individual Benefits, Practical Social Benefits, Benefits to Humanity, and Personal Aesthetic Benefits (Figure 3). Some of the participants endorse all four of these rationale Domains, while others endorse subsets (e.g., Practical Individual Benefits + Practical Social Benefits, or Practical Individual Benefits + Personal Aesthetic Benefits).

FOCI OF RATIONALE DOMAINS		**Scale of Focus**	
		Individual	*Group*
Utility of Focus	*Practical*	"Practical Individual Benefits" Domain	"Practical Social Benefits" Domain
	Abstract	"Personal Aesthetic Benefits" Domain	"Benefits to Humanity" Domain

Figure 3. Domains of rationales for scientific literacy.

All the participants agree that the pursuit of scientific literacy is a separate goal from the 'science pipeline,' i.e., developing scientific talent so that the country may have an adequate supply of scientists, engineers, doctors, etc. Scientific literacy is thought of as an expression of equity, as opposed to the perceived elitist nature of the pipeline goal. The science educators I interviewed do not seem overly concerned about the quality or number of scientists we have in the country or world today. Rather, they are genuinely concerned for average individuals and the public.

Participants generally view the concept of 'scientific literacy' as encompassing a continuum spanning from illiteracy to highly competent. They do not view it "typologically" (Bybee, 1997), i.e., as an 'all or nothing' situation. Perhaps only the mentally disabled or very young are considered scientifically illiterate. Thus, everyone who has a 'normally' functioning brain is scientifically literate at some level; and different individuals are scientifically literate to different degrees (Bybee, 1997). (This implies that the goal of universal scientific literacy has already been accomplished to some extent!) Another way to look at this is to say that everyone is capable of becoming scientific literate to some degree.

Points on which Participants Disagree or Diverge

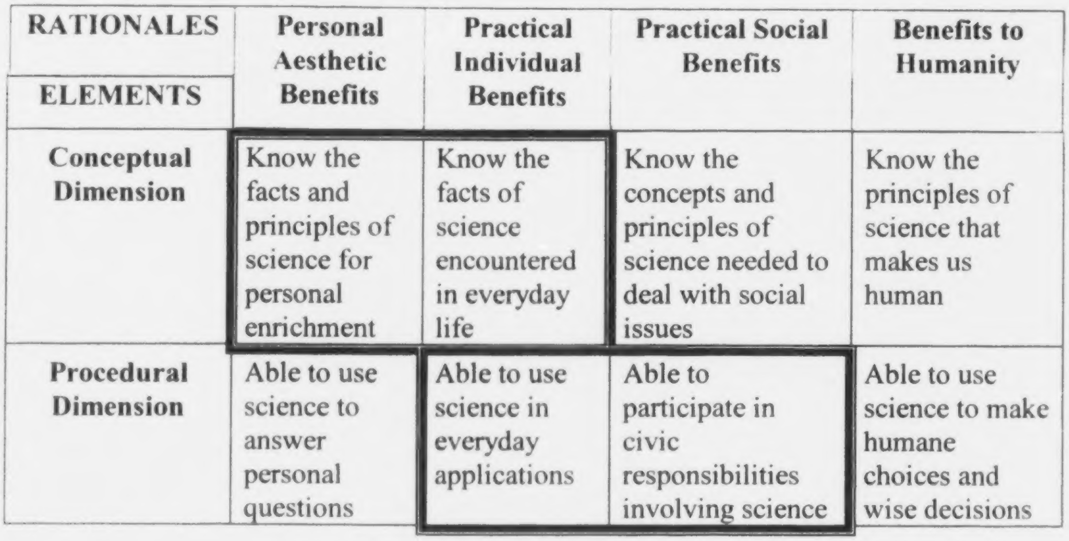
The most significant divergence in participants' views on scientific literacy occurs in their emphases on Dimensions of elements and Domains of rationales. Some emphasize the Conceptual Dimension, others the Procedural Dimension, and still others give nearly equal emphasis to these two Dimensions of attributes of the scientifically literate. Similarly, one participant emphasizes rationales that promote scientific literacy for personal development and application, several others endorse scientific literacy for its practical benefits, and the remainder support scientific literacy for both personal and social reasons, as well as for practical and abstract purposes.

None of the participants endorse exactly the same list of elements for scientific literacy, and in fact, most of their lists appear quite different. Of the 36 elements of scientific literacy coded from participants' interviews, more than 75% of them are endorsed by 5 or fewer of the participants, and in fact about 40% of the elements have the support of only one or two participants. In other words, in terms of gross numbers at least, participants' views on the elements of scientific literacy diverge more than converge.

In general, I did not ask participants, 'Should scientific literacy include "X" element?' because that would have been putting words in their mouths, in my opinion, and it would not reveal the elements that the participants believed to be most essential. Thus, a participant might not disagree with the inclusion of a given element, but simply failed to mention it during the interview. However, in some cases participants brought up (potential) elements and then dismissed them from consideration, e.g., Dr. Kellogg said that some people include vocabulary, but she does not consider that to be an essential aspect. In fact, there is quite a bit of disagreement about a few of the non-universal elements. For example, while some participants endorse the idea that the scientifically literate should be able to "engage in inquiry" on one's own, i.e., to actually 'do' science, to a certain extent (a Procedural element), others explicitly spoke against this element and said that it had no part in deciding who is scientifically literate and who is not. Another point of contention is the degree to which it is necessary for the scientifically literate person to have an understanding of the interrelations of science, technology, or science, i.e., to have an understanding of the STS perspective.

Categories of Views on Scientific Literacy

My findings suggest that, when examined on a fine-scale level, participants' views on the elements of scientific literacy are more different than they are alike, i.e., they have very diverse views about the attributes necessary for someone to be considered scientifically literate. However, on a gross scale their conceptions of scientific literacy seem to fall into three Categories that encompass a combination of the Domains of Rationales they support, and the Dimensions of Scientific Literacy Elements they emphasize. First, there is a 'Personal Scientific Literacy' category, which emphasizes the properties of the Conceptual Dimension of elements and a personal-scale focus of rationales for scientific literacy (Figure 4). A secondary emphasis on the Affective Dimension of elements of scientific literacy is also present in the one participant who holds this view. In this view, scientific literacy mainly means knowing and understanding a broad range of science concepts, including a good command of the vocabulary of science, so that one may use science in everyday life and for personal enrichment. An understanding of science includes an appreciation for its history. The scientifically literate individual is able to understand science communications in the public media, and also able to communicate science to others. This view also holds that it is important for an individual to develop an interest in science during school in order to be motivated to learn more science after formal schooling has ended.



RATIONALES **ELEMENTS**	**Personal Aesthetic Benefits**	**Practical Individual Benefits**	**Practical Social Benefits**	**Benefits to Humanity**
Conceptual Dimension	Know the facts and principles of science for personal enrichment	Know the facts of science encountered in everyday life	Know the concepts and principles of science needed to deal with social issues	Know the principles of science that makes us human
Procedural Dimension	Able to use science to answer personal questions	Able to use science in everyday applications	Able to participate in civic responsibilities involving science	Able to use science to make humane choices and wise decisions

Figure 4. Framework of scientific literacy.

Note. The bold lines outline two of the Categories of Scientific Literacy Views (upper = Personal Scientific Literacy; lower = Practical Scientific Literacy). The third Category (Formal Scientific Literacy) encompasses all 8 of the knowledge and ability cells. Note that the Affective Dimension is not shown because it does not seem to add useful distinctions for categorizing views.

'Practical Scientific Literacy' is a second Category of Views On Scientific Literacy (Figure 4). The properties of this Category include the Procedural Dimension of elements and a practical-utility focus of rationales for scientific literacy. A secondary emphasis on the Affective

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Dimension of elements is sometimes associated with this view. In this view, the scientific literate person can use science in everyday life and for social/civic purposes. To do so requires being able to acquire information about science on one's own, which in turn requires being able to decode science communications in the public media. Using science also means applying scientific "habits of mind" (Rutherford and Ahlgren, 1990). The scientifically literate person knows some of the basic concepts of science, and has an understanding of the relationships between science and society. Finally, but very importantly, the scientifically literate person has an appreciation for science, but at the same time he or she possesses an awareness (or attitude) that science should not be endorsed without question.

The third Category of Views of Scientific Literacy among the participants is the 'Formal Scientific Literacy' Category (Figure 4). The properties of this Category include the Conceptual and Procedural Dimensions of elements, and all four Domains of rationales, including: Practical Individual Benefits, Practical Social Benefits, Benefits to Humanity, and Personal Aesthetic Benefits. Some participants in this category emphasize certain Domains and/or Dimensions slightly more than others, but give weight to them all. In this view, scientific literacy means knowing science concepts, as well as understanding the broad principles of science. The scientifically literate person knows something about the nature of science, e.g., that it is a process involving inquiry, and that it has limitations. An understanding of science's relation to society is also expected. The scientifically literate person can acquire information about science on one's own, understand science-related stories in the popular media, and perhaps be able to communicate science to others. They should be able to use science in everyday life and in participating in civic (democratic) processes. The scientifically literate person also has an appreciation for and interest in science, and a desire to "stay up to date" with science in the news.

Furthermore, they should have a greater appreciation for life, nature, and humanity in general due to their scientific literacy.

There are a number of other potential Categories of Scientific Literacy Views, i.e., combinations of Dimensions of elements and Domains of rationales, that might be extant but which were not found in this study. It could be the small sample size and the relative uniformity of the group examined here contribute to the small number of Categories discovered. That is to say, if more university science educators were interviewed, or if members of other stakeholder groups were examined—such as teachers, the public, or legislators—then other Categories of Scientific Literacy Views might become evident, such as 'Knowing Science for Social Reasons,' 'Using Science for Abstract Purposes,' etc.

Again, I think it is important to emphasize that although I am able to classify participants' views on scientific literacy into a relatively small number of Categories, I do not want to imply that there is a high degree of unanimity within a given group at the present time. This is not necessarily the case, because when their views are examined on a finer scale, they often put their emphases on different elements and rationales from one another.

It would be useful to see if science educators' views of scientific literacy match those of the public, legislators, and science teachers. If these groups do not have similar visions then they may be working at cross-purposes. My relatively simple framework that combines the elements and Dimensions of the scientific literacy concept with the rationales or purposes for promoting the goal could be helpful in deciding what to look for in other groups of stakeholders. That is, applying the Framework of Scientific Literacy Views could help examine extant views and promote discussion of possible future directions to take in the pursuit of scientific literacy in the

United States both within science education circles, and between different groups of stakeholders.

Implications

Comparison of Implications of the Categories

If science educators hold different views on the elements and rationales for scientific literacy, it follows that they may also disagree about the ways to achieve the goal. (Of course, it is possible that they will agree on the *means* even though they have different *ends* in mind.) In this section, I will hypothesize some *general* implications for policy, programs, and practices for each of the three categories (see Table 2 for a summary). In terms of policy, I will focus on whether or not national/state standards and standardized testing are supported by the various viewpoints. By 'programs,' I mainly mean the focus of curricula that the view might support, and whether or not textbooks would be useful. And by 'practices,' I am referring to general instructional emphases (e.g., hands-on exploration versus lecture) and the role of the teacher in the classroom. The reader should note that I am not attempting to 'cover all the bases,' thus I do not address such issues as budgets, classroom resources and facilities, class period structure (block versus traditional), differentiation (e.g., how to address exceptional children's needs), relationships of science to other subject areas, particular instructional models (e.g., 5E model) or educational materials (e.g., commercial science kits), and technology's roles. These issues would have to be reviewed on a much finer scale than I can do based on the data I have gathered for this dissertation. Such considerations would also have to include other factors, such as individual grade level, type of school (e.g., urban versus rural), and student population.

Table 2

General Implications for Each of the Three Categories of Scientific Literacy Views

Categories	Policies supported	Programs advocated	Practices endorsed
Personal	Universal standards useful, but not essential. Standardized testing could be individually diagnostic, and largely memory-based.	Curricula that emphasize a broad range of concepts and principles of science. Textbooks are useful.	Teachers work with students to set individual goals based on personal needs and desires. Hands-on instruction less frequent as students mature.
Practical	Universal standards useful. Standardized testing is performance based.	Curricula emphasize procedures more than concepts. Textbooks not necessary.	Students engaged in inquiry activities, especially investigating personal and social problems. Teacher is guide, not sage.
Formal	Universal standards essential. Standardized testing necessary; combination of memory- and performance-based questions.	Curricula emphasize balance of breadth and depth, content and process. Textbooks are useful.	Both traditional lecture and inquiry practices encouraged, especially at the higher grade levels. Teacher is both sage and guide.

Implications of 'Personal Scientific Literacy' Category

The emphasis of the 'Personal Scientific Literacy' view is on knowledge and understanding of science that can either be used in everyday life, or that the individual will find interesting and personally enriching. From a policy perspective, universal standards and benchmarks for school science are probably not necessary to promote this view of scientific literacy. Standards and benchmarks might be useful as guideposts, but they are not essential. The focus is on the individual, not the group. As Dr. Johnson views it, if we "Prepare teachers who are knowledgeable, caring and thoughtful, and they will develop [their own] high standards." The idea is that the teachers will get to know their students as individuals and help them to learn as much about science as they can. Standardized testing would only be useful insofar as it is diagnostic, i.e., its purpose is to help the individual student know where he or she stands, and how the individual school (system) is doing in reaching goals it sets for itself.

To be consistent with this category, curricula should emphasize a broad range of the concepts and principles of science, not a depth of any particular branch or topic in science. Textbooks would be helpful in this regard.

To promote 'Personal Scientific Literacy,' younger students should regularly be engaged in hands-on explorations. However, this practice should be reduced as students progress through school and are able to handle more abstract concepts, i.e., more mature students do not necessarily need to actually experience a phenomenon first-hand, but instead can learn simply by watching, reading, and/or listening. Accordingly, it would seem that lecture (and reading of textbooks) would be the hallmarks of practices found in the senior (12th) grade science classroom. Learning would be directed toward discipline-based concepts, and therefore knowledge would be acquired through the transmission of information rather than through personal discovery. Although the classroom could focus on individual student's interests, the teacher would be a lead figure in the classroom.

Implications of 'Practical Scientific Literacy' Category

The emphasis of the 'Practical Scientific Literacy' view is on using science either for one's everyday life or for social/civic roles. Note that some science knowledge is required in order to be able to 'use' science. Due to the emphasis on the social level, universal standards and benchmarks are probably useful to promote this view. Standardized testing would be promoted to ensure that benchmarks are being met. However, the type of testing would most likely be performance based rather than memory based, i.e., students would be asked to do things rather than answer multiple choice questions.

Curricula that promote 'Practical Scientific Literacy' should emphasize learning science process skills, as well as decision-making and information-processing skills. Depth of understanding of the unifying principles of science is seen as more important than a breadth of knowledge of science concepts. Curricula would be problem-based, and would not necessarily be centered on the distinct science disciplines, i.e., students might be in integrated science courses, not biology, chemistry, etc. Accordingly, textbooks are not necessarily required in this view of scientific literacy. Some promoters of this view would endorse Science-Technology-Society approaches to teaching and learning.

Those who hold the 'Practical Scientific Literacy' view would encourage self-discovery of science concepts, principles, and applications. Accordingly, students are to be engaged in inquiry, especially with regards to personal or social problems. Since students would spend a majority of their time engaged in problem solving, teachers would spend little time lecturing and would not be the center of attention in the classroom. Students would learn from real-life experiences and from their interactions with others—including other students—more than they would from reading books.

Implications of 'Formal Scientific Literacy' Category

I label the last category to be discussed as 'Formal Scientific Literacy.' This is a broad conception of scientific literacy and a correspondingly wide range of programs and practices is necessary to promote this view. Universal standards and benchmarks are useful means of ensuring that everyone has an equal opportunity to learn meaningful science. Standardized testing would be a mixture of memory-based (multiple-choice) questions and performance-based tasks (e.g., open-ended questions).

The curricula associated with this view emphasize a balance of breadth and depth, as well as a balance of content and process. Textbooks would be useful in this regard, though problem-based units would also be valuable additions to the curriculum.

Both self-discovery and direct teacher transmission of science concepts, principles, and applications are compatible with the 'Formal Scientific Literacy' view of scientific literacy. Accordingly, both traditional lecture and inquiry practices would be encouraged, especially at the higher grade levels. At times, then, the teacher would be the sole leader of the class, while at other times the teacher would be a 'guide on the side' facilitating student learning.

Overall Implications

The three views I have classified for the study participants seem to be at odds with one another. For example, the first two categories discussed above seem to be philosophically antagonistic. That is, a person holding the 'Personal Scientific Literacy' view is really pursuing a different goal than someone who advocates 'Practical Scientific Literacy.' The first person would promote learning science concepts for individual development, and would say that scientific literacy requires a broad knowledge (and interest) in the sciences. Only if one possesses this knowledge can one hope to use it. Further, knowing science is enlightening and enjoyable, and perhaps even ennobling. On the other hand, the promoter of the 'Practical Scientific Literacy' view endorses learning the procedures and processes of science for practical application in one's daily life and civic roles. While scientific knowledge is important in this view, it is seen as being ephemeral and somewhat impotent if one does not understand how to use it. Indeed, this view promotes learning about scientific principles in depth so they can be applied to new situations one encounters in life.

It is tempting to view the first two Categories as being subsets of 'Formal Scientific Literacy' Category; or, alternatively, seeing the third category as being some sort of composite or compromise between the first two (and other possible views, as well). However, I think to do so would be misleading. None of the participants who espouse the 'Formal Scientific Literacy' view explicitly (or even implicitly) state that this is some sort of composite or compromise view. They do not see 'Personal Scientific Literacy' and 'Practical Scientific Literacy' as offshoots of their broader view. Rather, members of this third group all have in mind a broad array of rationales/purposes for scientific literacy, and as a consequence they require a correspondingly broad array of elements to achieve scientific literacy.

The participants who hold the first two views I discussed would probably say that 'Formal Scientific Literacy' is a self-incompatible goal, not only for the reasons given above but also because of the limits on time (and resources) for science education. There is simply not enough time to give all students both a breadth and depth of science knowledge, as well as facility with scientific processes and procedures (Shamos, 1995). Certainly, it is exactly this view of scientific literacy that is at the heart of Morris Shamos' (1995) criticisms. That is not to say, however, that these science educators agree with Shamos' proposition that the goal of scientific literacy ought to be scrubbed and replaced by "science awareness" (Shamos, 1995, p. 216). Rather, they are simply arguing for a more limited view of scientific literacy.

Conclusions

The fact that there are different views on the meaning and purposes of scientific literacy was taken as a 'given' at the start of this study, and indeed came as no surprise to my participants. That is, these experts are aware of different opinions on the subject of scientific literacy, and many discussed how their own views compared to others. They recognize that scientific literacy might mean different things in different contexts. For example, different societies (e.g., developing world countries) would most likely emphasize different aspects of scientific literacy than the United States. However, some of the participants are bothered by the diversity of views on the meaning of 'scientific literacy' to such an extent they are willing to abandon the term, but not the substance of the goal. Others are nonplussed. They recognized that the concept of scientific literacy has evolved over time, i.e., the elements and rationales for scientific literacy have changed in emphasis, if not in substance, over the years. They believe this ever-changing nature of the concept has contributed to some of the criticism that 'scientific literacy' is an "ill-defined" and "vague" concept. They believe that such publications as the *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) are now bringing more consensus to the meaning of the concept. However, it is my interpretation of the interview data that there is probably not as much consensus as the participants believe. For example, there appear to be three main Dimensions of elements for scientific literacy, one having to do with the necessary knowledge, another with the requisite skills, and a third that has to do with dispositions and values possessed by the scientifically literate. The participants did not agree on which of these Dimensions should be most emphasized, or even on the appropriate elements to include in any of the Dimensions. Thus, when the participants feel someone else's view of scientific literacy is compatible with their own, they might be fooling themselves because they are filtering their interpretations through their own belief systems.

Participants also discussed how scientific literacy has also increased in importance (centrality) as a goal for science education. They view the goal as being separate from, and perhaps in competition with, the 'science pipeline' goal, which used to be the dominant goal of science education in the 1960s and '70s. As Shannon (1962) puts it: "Education in a democracy makes two somewhat conflicting demands: to discover talent and provide opportunities to nurture that talent, and to raise the level of the average student" (p. 253). Even though the distinction between these goals is rather clear in their minds, they recognize that it is not so clear to science teachers or the general public, and this confusion has no doubt also contributed to misunderstandings about the meaning of 'scientific literacy.' While 100 percent of the public may never become scientifically literate to a high degree, most of the participants agree that working towards that goal should be the main focus of science education, especially in the pre-college schools. They feel that college is the appropriate time for students to specialize.

Participants recognize that others view scientific literacy differently from themselves, and some seemed to think that their views on scientific literacy were different enough to be considered in competition with other views, if not totally incompatible. This is especially evident among those who emphasize Procedural elements over Conceptual elements, i.e., these experts think those who view knowledge as the most important aspect of scientific literacy are actually doing a disservice to learners (and hence, the public). However, most participants seem to feel that differences in views are most often related to emphasis or degree rather than real substance or kind.

The experts generally support benchmarks and/or standards. However, one implication of my work is that until purposes and meanings of scientific literacy are clarified, developing standards to achieve scientific literacy is premature.

The bottom line is that while these experts generally think of scientific literacy as a useful concept, they do not necessarily think of it as a specific, achievable thing. Rather, it is a desirable destination to travel towards even though we may never be able to reach journey's end.

Recommendations

It is not inconceivable that science educators will soon be called upon to publicly defend their enormous expenditures of the public's tax dollars (not to mention children's valuable school time) in the pursuit of a goal that according to some (e.g., Shamos, 1995) is not achievable or in the public's best interests. It seems only logical, given the present criticisms and state of reform in science education in the United States, that science educators should seriously examine the goal of scientific literacy so they can formulate coherent and effective policies, programs and practices for achieving it—or, so they can abandon it altogether in favor of a more desirable goal. Below, I summarize 2 recommendations that stem from my study of science educators' views on scientific literacy.

Recommendation 1

Who is considered scientifically literate (and who is illiterate) depends on how 'scientific literacy' is defined. Yet, the participants of this study appear to have widely divergent views of what constitutes 'scientific literacy,' even though all of them are university science educators in the United States and are quite familiar with the concept (or at least their version of it). Therefore, while the participants may think they are working towards a common goal, in fact they may be pursuing entirely different ends. In fact, I have shown that within the 9 participants' of this study there are at least 3 different Categories of views of what 'scientific literacy' means. If time and resources for science education were unlimited, then these views might be compatible. But time and resources for pre-college science education are in fact limited. Consequently, these university science educators appear to be espousing and working towards 3 competing goals. Thus, the differences in their views could be leading to confusion among the wider audience of science teachers, program developers, policy-makers, etc.

Given that this study is based on a small number of participants, I do not want to overly generalize. Rather, I would recommend that more studies be done to examine the views of a wider range of science teacher educators, as well as other stakeholders (e.g., science teachers), to see if the different views found among the participants of this study hold more generally, as well as to see if other views are extant.

Recommendation 2

If it is found that a diversity of views on the meaning of 'scientific literacy' exists more generally, then science educators need to decide *if* steps should be taken to reach consensus. Some might say that having a consensus on the meaning of 'scientific literacy' is a desirable aim, because it would directly influence such things as why we teach science, what science should be taught and to whom, and how science should be taught. I have suggested that having different views leads to competition for resources. Alternatively, some science educators may think a diversity of views on scientific literacy is actually healthy and needs to be encouraged. Some people consider a single consensus view to be too limiting and incapable of serving the range of diverse interests among school children or the public (e.g., Apple, 1992, 1993a, 1993b, 1996; Ohanian, 1999; Roberts, 1983). For example, a single consensus view of scientific literacy might imply that across the country uniform standards, instructional methods, assessment instruments, etc. should be applied. Some educators worry that national (and even state) standards erode local control over education, and therefore limit important connections between communities and their schools (Rural Challenge, 1999). These educators also fear that uniform standards require schools to adopt relatively narrow curricula and teaching methods that sever crucial linkages between students' lived experiences and rigorous academic content (see e.g., Eisner, 1995). Having a single vision of scientific literacy may in fact be license to rationalize the avoidance or even destruction of other knowledge systems that are deemed inferior (see Stanley and Brickhouse, 1994). That is, the traditions of non-dominant cultures, such as the American Indians, might be unjustly ignored or even demeaned if a single view of scientific literacy is promoted. Thus, it would behoove science educators to discuss whether or not consensus on the goals of science education is a desirable aim.

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Integrated Instruction in University Methods Courses: Applying Science Technology Society

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Despite the diversity of opinion regarding the value of integrated instruction (Czerniak, Weber, Sandmann & Ahern, 1999), the desire to create more efficient and authentic learning experiences in the science classroom continues. The challenges of preparing students to become effective science teachers have contributed to generously to the teacher education literature. In particular, the desire to have students instruct science from an integrated and interdisciplinary (Abruscato, 1996; Carin, 1997; Howe and Jones, 1998; National Research Council, 1996) perspective provides challenges to a methods course instructor offering instruction in a standard content-specific format. Science education curriculum and program documents also support these initiatives (American Association for the Advancement of Science, 1989; National Council for Social Studies, 1994; National Council of Teachers of Mathematics, 1989; National Research Council, 1996). These academic and organizational efforts have been buttressed by a proliferation of instructional packages, such as the AIMS and GEMS programs, which promote integrated instruction. Modeling the desired instructional strategy is difficult due to the perceived barriers of the content disciplines, knowledge of pedagogy, and lack of existing models (Huntley, 1999).

The purpose of integrated, interdisciplinary approaches is to provide students with a unified view and opportunities to connect learnings that are related to each other (Czerniak, Weber, Sandmann & Ahern, 1999; Knapp, 1996; Sealy, 1995; & Wasley, 1994). For example, when experiencing an integrated curriculum the learner develops skills in language arts and the skills can be used to learn about social studies, science, and other subjects (Tanner, 1997). Educational experts believe that integrated curriculum has a natural home when a teacher wishes to be more student centered and problem based (Gardner, 1993).

The benefits of an integrated, interdisciplinary approach to teacher education are not clearly delineated. Critics of the integrated approach believe that students should reach "deep understandings across disciplines by first reaching deep knowledge within the discipline (Gardner, 1993). Many of those same critics believe that when teachers use an integrated approach one discipline may overshadow others, there is not time to explore powerful subject-based ideas, less content is learned and subject matter depth is lost (Knapp, 1996). Advocates of the approach believe that integrated instruction improves retention, focuses on problem based learning and is more student centered. It is particularly appealing to the middle school movement and team teaching (James, Lamb, Householder, & Bailey, 2000; Willis, 1994).

The issues are even more complex when considering the benefits of an integrated curriculum in teacher education programs. Are integrated methods courses the most helpful approach to help future teachers acquire the pedagogical skills necessary to teach science and other subjects? Teacher educators who attempt to model integrated curriculum during methodology courses have "little empirical evidence" that integrated, interdisciplinary teaching improves learning (Czerniak, Weber, Sandmann & Ahern, 1999; Hough & St. Clair, 1995; Meir, Cobbs, & Nicol, 1998), though much "testimonial" evidence makes strong claims for its value. However, many new standards advocate and recommend that curriculum reflect some aspects of integrated, interdisciplinary approaches (AAAS, 1989; Knapp, 1996; NCSS, 1994; NCTM, 1989; NRC, 1996; Willis, 1994).

Logistical issues related to time and subject matter coverage also serve as challenges to teacher educators. Integrated teaching requires far more teacher preparation and time to collaborate than traditional approaches (Louisell & Descamps, 1997). Materials, lessons plans, and classroom management plans must be closely coordinated and connected. Planning and teaching together as a team requires coordinated effort and blocks of common time. Few learners have been exposed to a truly integrated approach. New teachers who were raised in a system designed to encourage specialization must be exposed to integrated curriculum to gain expertise, especially in math and science (Pang & Good, 2000; Wasley, 1994). When implementing integrated curriculum, new teachers must be taught a see how to guide their students to use group work and engage in collaborative tasks.

Science Technology Society as Integrated Instruction

John Dewey wrote of "liberating the student from narrow utilities." The science-technology-society (STS) movement represents an attempt to accomplish that goal through an interdisciplinary approach to those three content areas, providing a coherent conceptual scheme for integrating classroom instruction. The beginnings of the STS movement can be traced to efforts in several European countries, as well as some domestic attempts during the early 1960s (Yager, 1990). According to Yager, the effort in the United States was finally given an added emphasis in the early 1980s as educators sought to create a science program that would involve all students--not just the one or two percent who would study science in college. Among the goals of the STS program is to provide real-world connections for students between science content and societal issues, providing students with an authentic means of integrating instruction between and among the disciplines (Lumpe, Haney, and Czerniak, 1998). The process would give the student practice in identifying potential problems, collecting data with regard to the problem, considering alternative solutions, and considering the consequences based on a particular decisions (Yager, 1990). This social action outcome of instruction finds support in contemporary definitions of scientific literacy (American Association for the Advancement of Science, 1989; Kumar & Berlin, 1996; Ramsey, 1993)

Aikenhead (1992) provided a conceptualization of the STS program. Technology is conceived as the interface between science and society. As citizens are called upon to make decisions, they typically utilize technology as a means of securing information, as well as a tool for the implementation of solutions. The pivotal role served by technology can provide a means of action and of investigation in the STS curriculum. This conceptualization also implies the nature of science as a field within all of society.

Both social studies educators and science educators have discussed the benefits of the STS curriculum approach to their respective fields. From the social studies perspective, Remy (1990) argued that STS curriculum can contribute to the goal of promoting civic competence by providing an understanding of the social issues generated by science and technology and by offering students the opportunity to practice decision-making related to these issues. Furthermore, he recommended STS as a means of promoting interdisciplinary connections, developing students' appreciation for the role of science and technology in shaping our democratic heritage, and resisting anti-scientific and pseudo-scientific rhetoric from "antagonists of modern science and technology." Remy (1990) concludes:

> We need to find ways to devote some attention in the curriculum to the concepts of science and technology as symbiotic enterprises, their origins and development in Western civilization, their functions in contemporary American life, their power and limitations in solving problems, and the benefits and risks associated with their applications to society (p.205).

The National Council for the Social Studies (NCSS) adopted STS as one of the ten thematic strands of its curriculum standards (NCSS, 1994). The description of STS provided in the NCSS standards document notes that STS involves questions that are key to the social studies curriculum, such as

> Is new technology always better than that which it will replace? What can we learn from the past about how new technologies result in broader social change, some of which is unanticipated? How can we cope with the ever-increasing pace of change, perhaps even with the feeling that technology has gotten out of control? How can we manage technology so that the greatest number of people benefit from it? How can we preserve our fundamental values and beliefs in a world that is rapidly becoming one technologically-linked village? (NCSS, 1994. P. 28).

Although the STS approach is typically described in the secondary school context, the NCSS recommended the STS curriculum as appropriate and relevant to social studies education at all grade levels. For example, the performance expectations for this standard indicate that elementary students should be able to:

- Identify and describe examples in which science and technology have changed the lives of people.
- Identify and describe examples in which science and technology have led to changes in the physical environment.

- Describe instances in which changes in values, beliefs and attitudes have resulted from new scientific and technological knowledge.
- Identify examples of laws and policies that govern scientific and technological applications.
- Suggest ways to monitor science and technology in order to protect the physical environment, individual rights, and the common good (p. 43).

The social studies education literature tends to emphasize STS as an approach to the study of how science and technology impact society. Science educators, however, tend to focus on how STS can achieve the goal of promoting scientific literacy – using science to achieve social good. The purpose of school science in an STS framework then is much broader than the typical discipline-centered, textbook-driven science course. Zoller (1992), for example, described the need for all students to be informed as to the content and process of science, but with the understanding that science and society impact each other. Brunkhorst and Yager (1990) found that exemplary science programs that use an STS framework tend to:

- Emphasize science for all students
- Emphasize higher order thinking skills across content areas
- Be interdisciplinary in nature
- Be hands-on, student-centered, minds-on programs
- Include student action plans, projects, field experiences, and field research
- Utilize many outside resources
- Tie STS issues to the traditional content of the course

- Structure evaluation to assess a variety of domains and include awareness and reasoning components
- Produce students who do as well (if not better) than students in typical science courses when standardized tests and/or textbooks are used (p. 63).

These characteristics clearly match the current notions of what constitutes scientific literacy. The American Association for the Advancement of Science (1993) offered a similar description of scientific literacy:

> Science literacy enhances the ability of a person to observe events perceptively, reflect on them thoughtfully, and comprehend explanations offered for them. In addition, those internal perceptions and reflections can provide the person with a basis for making decisions and taking action. (AAAS, 1993, p. 322)

More recently, Leslie (1999) addressed the need for reestablishing a conversation regarding the role of STS in education. He argued that the need to connect all students with the role of science and technology within a broader societal framework is essential. This theme resonates with the purpose behind the title of the American Association for the Advancement of Science's *Science for all Americans*.

Further underscoring the need to make education available to all Americans, the STS approach has value beyond the disciplines of social studies and science in terms of meeting the needs of urban youth (Waks, 1991), African-American youth (Jegende, 1994; Solomon, 1994), women (Rose, 1994), and other marginalized ethnic groups (Rampal, 1994). Caseu & Norman (1996) suggest that STS may have untapped possibilites for engaging diverse learners in science. May (1992) suggested that, when implementing the STS curriculum, one must seriously consider the "whats and whys" of this approach. In her view, the STS approach can, if unleashed irresponsibly, represent an expression of a westernized, secular, science-driven culture. Thus, some degree of sensitivity is needed with respect to the belief systems of the students who will participate in the program. In our view, the potential dichotomies between western and nonwestern, secular and sacred, represent an area for consideration within the STS framework.

Teacher Preparation for STS

As with any curriculum initiative at the K-12 level, it is essential that the STS approach be implemented with a degree of caution; lest it be considered this week's fad by a cynical cadre of teachers (Bragaw, 1992). Rutherford (1988) argued that, while some may consider STS to be another trend in education, it actually has a great degree of staying power given the increasing volume of information in society and the importance of scientific and technological developments in the daily lives of citizens. If the STS approach is to be implemented appropriately, the preparation of teachers for this task is of paramount importance.

Several researchers have explored the issue of teachers' perceptions of STS. Mitchener and Anderson (1989) examined teachers' perceptions regarding the creation and implementation of an STS curriculum and identified barriers such as, concerns over content, discomfort with grouping, uncertainties about evaluation, frustrations about student population, and confusion over the teacher's role. Rhoton (1990) also investigated teachers' perceptions and found that teachers had a high degree of perceived need in terms of both adequate information and preparation. Interestingly, Rubba's (1989) study suggested that while teachers were confidant in their own ability to understand STS content and to teach it effectively, their students' abilities to understand the content was not confirmed by the data. The author suggests that teachers' perceptions of high interest activities are not consistent with what students perceive as high interest activities.

Further support for the application of an STS approach comes from the work of Wiesenmayer and Rubba (1999), who found evidence demonstrating a strong link between student participation in an STS curriculum and significant (positive) changes in student citizenship behaviors. Clearly the participation of students in high interest activities has a positive influence on their citizenship behaviors. This connects strongly with Rubba's (1989) earlier assertion that the activities must be meaningful to students for the benefits of STS instruction be acquired.

Rubba (1990) also examined the dynamics of teacher-teacher interactions and suggested that there is a strong need for interdisciplinary cooperation between teachers if STS is to be successful. Similarly, Yager, Mackinnu, and Blunck (1992) found that teachers need more training in terms of their exposure to and implementation of an STS program if it is to be effective. Schibeci (1990) echoed these findings as he determined that adults display very little in the way of basic scientific and technological literacy.

Among elementary students, Thirunarayana (1998) determined that elementary students can develop meaningful conceptions among science, technology, and society related topics that offer a personal relevance to themselves. However, in terms of environmental issues, they still evidenced some difficulty expressing clear conceptions of the relationships among the issues. Thirumarayana suggested therefore that before STS instruction be implemented, teachers must first build upon their interests and use that to develop the conceptual understanding. One can see that this remains a challenge if

Schibeci's (1990) earlier assertion that adults lack adequate knowledge in terms of scientific and technological literacy is assumed.

Implementation of an STS Project for Preservice Elementary Teachers

In an effort to address the need to prepare preservice elementary teachers for integrated instruction, the investigators elected to use STS as a means of developing student experiences. An STS project was selected and assigned as a requirement for the undergraduate elementary education students enrolled in our elementary social studies methods and elementary science methods courses. The project involved a total of some 120 elementary education students across three sections of each course. These students were enrolled in a "block" of methods courses that typically includes science, social studies, language arts, reading, and assessment during the semester prior to their student teaching experience. During this semester, these preservice teachers also complete a full-time, three-week internship in an elementary or middle school.

Each of the instructors taught three sections of their respective undergraduate methods courses. There were approximately 30 students in each class. The instructors taught two groups of students in common. The STS assignment was available to all students in the courses they taught, but among the two groups of students whom the instructors shared the STS assignment could be used for credit in both the science and social studies methods courses. Students in both classes, furthermore, could select the STS assignment as one option out of three (other options in the courses included software evaluations, constructing discipline-based instructional unit, constructing a WebQuest, or a reading/seminar experience), making participation in the STS project optional. In all, some 70 STS assignments were completed.

The science and social studies methods instructors developed the STS experience for their preservice teachers. These individuals shared students in two of the methods course blocks. The first STS project included five phases: identification and definition of an issue, exploration of the issue, proposal for action, development of lessons, and reflection on the process.

An additional component of the experience was making use of resources from the School of Nursing at the university, in support of their efforts to promote awareness of health care careers, particularly among nurses. The authors of the study required that the STS topic the students developed be focused around a health care issue. To support this, the School of Nursing made resources available to assist students in their development of the topic. These resources included a web site, a presentation by members of the faculty, and a commitment to being available to students as they pursued the development of the STS project.

In an attempt to meet the needs of students in the teacher preparation program, the authors of the paper designed a flexible approach for students to use while developing an STS investigation. The students were offered three approaches to meet the course requirements in terms of learning about STS as an instructional approach. One of the approaches required the students to actually engage in an STS investigation of their own. Students were asked to abide by the following steps to investigate and report back what they learned from the investigation. The phases of the project were as follows:

- *Identification*--Students identified an issue for investigation.

- *Exploration*--Students conducted research through library work, Internet searches, and personal interviews. Students examined multiple perspectives of the issue and the potential consequences of each of the possible solutions.
- *Proposal for action*--Based on the exploration, students proposed some action be taken to respond to the findings from the exploration phase.
- *Implementation of action*--This component of the experience could be accomplished in either one of two strategies:
    - Construct a display board and brochure, alerting the public at large as to the issues examined and their proposal for reasonable action in response to the issues. The displays were to be shared by posting them in a public location within the college of education.
    - Compose a letter to a person of influence (legislator, government official, newspaper editor) explaining the issues developed and the proposal for action. It was expected that the students submit the letter to the identified person of influence, and share a reply with the instructors, if one was received.
- *Reflection on the process*--the student was asked to compose a brief essay describing their interaction with the process and how they foresee this experience as having prepared them to teach in an STS framework.

The third option offered to students was based on an approach profiled by Varella, Monhardt & Monhardt (2001). Students were asked, in this option, to produce a unit outline for an instructional unit supporting an STS investigation. The student selecting this option was required to develop the following:

- *Description of the problem*--Compose a paragraph that defines exactly what this "problem," issue, or topic is, taking into consideration the grade level for which the unit was developed.
- *Establishing relevance*--Write a paragraph that might get your students interested in this topic.
- *Possible student questions*--Generate a list of ten credible questions that students might ask about this topic.
- *Possible resources*--Considering your student questions and the developmental/age level of your students, generate a list of possible resources that your students could utilize to find answers to their questions. These were to include both written and human resources.
- *Learning activities*--Submit a lesson plan in each of the following areas:
    - A guided discovery science lesson
    - A social studies lesson
    - A lesson to examine health careers that relate to the topic under investigation
- *Social action*--Write a paragraph that explains clearly what action could be taken by your students to address this issue. The action was to a task that could be completed by children at the age/developmental level for which they designed the unit.
- *Concepts*--List specific concepts within science and social studies that would be encountered in this unit.
- *Evaluation*--List possible means for assessing and evaluating students on the outcomes of this project.

Students submitted one of these assignments to receive course credit in both their science methods course and their social studies methods course. In each case, the assignment was worth approximately 10 percent of the entire course grade. Other assignments included traditional activities such as examinations, microteaching experiences, and class participation.

Methodology

Methodology for this investigation followed an action research approach. Given the role of action research as a means of reflecting upon and improving classroom experiences, the authors of this study, as university methods educators, sought to identify the challenges and obstacles to preparing students to create lessons within an STS framework.

The authors were guided by the principles of action research in our attempt to understand both the development of prospective teachers' knowledge and skills related to STS instruction and our own practice in facilitating these outcomes. Glanz (1998) defines action research as, "a type of applied research … that is conducted by practitioners to improve practices in educational settings." The primary difference between action research and other forms of research is that, "action researchers study their own practice, not the practice of others" (Wade, 1999, p. 75). An action researcher must adhere to the same guidelines for rigor in data collection and analysis standard in all forms of inquiry. The action research approach, however, allowed us to add an additional layer to the investigation.

Action research has traditionally been conducted in K-12 settings by teachers and administrators as a means of examining school practices, promoting staff development, and encouraging school reform (Corey, 1953; Glickman, 1993; Sagor, 1992). Recently, the notion of teacher educators as self-reflective practitioners has led to studies making use of the action research design in university settings (i.e., Wade, 1999). As relatively novice teacher educators, the authors both engage in a great deal of critical reflection regarding course assignments, teaching methods, assessment practices, and a host of other teaching issues. By engaging in action research, we were able to formalize and collaborate in this self-reflective process, as well as examine the student outcomes of our STS project (Milson & King, in press).

In addition to the instructional changes under examination by the methods course instructors, members of the university's nursing faculty were interested in the influence of conducting developing elements of the students instruction around issues related to nursing as a career. To this end, a pretest-posttest measure of student responses to a nursing survey was administered at the beginning and at the end of the semester. In this way, the nursing faculty sought to determine the extent of knowledge gains regarding nursing acquired during the research for the STS investigation.

Outcomes and Discussion

A number of outcomes were observed from the experience of actually engaging in a Science-Technology-Society investigation. The results provided the authors with some insights into the process of developing STS-themed instruction in their respective methods courses.

Support for the use of STS as an element of the elementary science and social studies methods courses came initially through comparing student knowledge gains from one semester to the next. Objective measures made from course examinations indicated that students obtained a better understanding of STS as an instructional approach in both the science and the social studies methods courses. The elements of STS were discussed by both methods instructors previously, but only so far as a classroom discussion and assessing their understanding through a written examination/multiple choice examination. To this extent, engaging students in an actual STS investigation demonstrated increased knowledge among students of the elements of STS instruction.

Greater awareness of STS as a theme for instruction was also observed through improved scores on course assessments. Students recognized STS as a means to implement interdisciplinary instruction. As with the first point above, student knowledge of STS, in general, increased as measured through course assessments. Understanding of purpose for STS was also evident during classroom discussions and responses to specific questions.

Students also better recognized the application of STS in content areas, promoting a coherent means of developing interdisciplinary instruction. Put succinctly, students obtained an improved understanding of the role that STS can serve as a means of developing interdisciplinary instruction.

The challenges experienced by the instructors were observed in three areas, devoted primarily to the project itself and the perception of how it was evaluated. One of the key points noted was the issue of motivation: students in the shared methods courses were more likely to carry out the STS-related assignment for the sake of efficiency—it gave them credit for two courses. Comments from students underscoring this point included the following:

> I thought it was interesting and I wanted a good grade.
> Because it counted for 2 classes.

Other students did indicate that carrying out the project themselves did, in fact, give them deeper insights into the nature of inquiry and STS-themed instruction, which was consistent with scores on examinations. Reflecting this position:

> I felt the project was very helpful in understanding STS development projects…
> I liked doing the assignment.
> I think STS projects are very useful. It gives students and teachers a *real* life purpose to learn science and technology skills and content. Not all students will be scientists, but for everyday living, STS shows how science applies. I LIKE IT A LOT!

For students who elected not to select the STS option, the primary reason given was that they did not want to have their choice of topics limited to issues that had a health care component included.

A perspective that emerged numerous times among the preservice teachers was the belief that the STS assignment was too much of a burden for students to complete during the semester or that the assignment was not perceived to be directly applicable to their career goals. A sample of students representing this point of view:

> The level of difficulty was too great.
> I thought it was not for an education class. It did not teach me anything about how to teach.

Some students rather stridently voiced their objection to the entire assignment:

> It was a waste of time. It was just a research project. It wouldn't help me in my classroom other than giving me another way to assign the same thing to my kids.
> I don't see how this project relates to teaching science.

Specific to the assignments, the authors noted a pattern emerging from the assignments submitted for course credit. In many cases, students struggled with the important skills of developing a position on a topic and developing coherent arguments to support their point of view. Given that the skill of collecting evidence and arguing for a position is a key component of inquiry-based science and with all major reform initiatives, this was most troubling.

These issues were underscored first by student reluctance to consider multiple perspectives for the issue they were examining. During the initial project development, considerable time and effort were expended to make this point clear. With one exception, no student stated that their position had changed during the course of their investigation. Student narratives sometime took on an element of self-parody: "I believe X, some people believe Y, but they're wrong/stupid/ignorant" does not depart significantly from several of the projects submitted.

Students also exhibited a disinclination to take a position. Frequently, after presenting arguments collected on either side of an issue, several students closed with a statement such as "as I have shown here, there are several issues to consider." Frequently, after presenting arguments collected on both sides of an issue, several students closed with a statement such as "as I have shown here, there are several issues to consider. As our state representative, what do *you* believe we should do on this matter?" This reluctance to use the data to make an informed decision was disconcerting, as considerable class time was devoted to the challenges of making decisions based on the data collected; perhaps the desire to not be perceived as wrong prevented these students from presenting their position.

Other students demonstrated a lack of understanding as to how the government functioned. In these cases, students would compose a letter to a legislator seeking legislative remediation, but contacting a member of the national congress to deal with a state or local issue, such as recycling in a school district. A significant number of students attempted to solve all of the challenges created by asking for legislation; other strategies such as economic boycotts, direct action by organized individuals to correct their identified problem, or contacting executive officers of corporations were never attempted.

In terms of developing science instruction in concert with their identified STS issues, students were challenged to implement science beyond a discipline-specific approach. The global approach to identifying science issues within the domain of an STS investigation proved problematic, as students were consistently unable to identify what science content/inquiry skills would be profitably engaged. The broader definitions of scientific literacy, with science representing, in part, argument and explanation, were not well addressed in most of the projects submitted.

The previously noted science and social studies instructional issues exacerbated instructional issues. The project was worth approximately 10% of the course grade in both the science and social studies methods courses. Students, however, demonstrated frustration that the grades were to count for credit in both courses--this occurred after multiple course credit was previously considered to be an advantage. It seems that the challenges they encountered carrying out the assignment--and arguing their points of view effectively--became a serious disincentive when they perceived the assignment as awarding them a B/C grade in two course assignments, rather than what they had anticipated would be an A/B letter grade.

Students also were frustrated by their belief that "all opinions are valid." While the emphasis by the instructors was on the quality of the argument, students received feedback on the quality of the arguments they offered in a very personal way.

From the experiences here, the instructors are still convinced as to the value of STS as a means of developing effective integrated instruction. To move beyond the challenges experienced during this investigation, several areas of improvement are suggested:

> Develop more experiences to help students learn to develop support positions via the use of data.
> Create more class experiences that demonstrate the means to develop interdisciplinary instruction through the use of real world problems.
> Proceed with caution when implementing interdisciplinary instruction. The high conceptual level of understanding required to effectively implement curriculum of this nature might better be reserved for students who have already taken an initial methods course.

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DILEMMAS OF TEACHING INQUIRY IN ELEMENTARY SCIENCE METHODS

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Dilemmas of Teaching Inquiry in Elementary Science Methods

Although the definition of inquiry varies among science educators, its presence is undeniable in current science education research and in reform documents, including national and state standards. Given its importance in reform documents and in the science education literature, addressing inquiry is essential in science teacher education programs. In our teaching of elementary science methods, we emphasize inquiry as a set of learning outcomes and as a teaching approach. However, our teaching of inquiry has created several teaching dilemmas for us, stemming from our students' lack of exposure to learning science through inquiry, our own limited experiences with teaching and learning through inquiry, and the variety of meanings for inquiry that we have constructed. These teaching dilemmas include our inability to provide sufficient inquiry-based science learning experiences given the time constraints we face, conflicts between modeling science as inquiry vs. teaching inquiry as a pedagogical strategy, and student attitudes toward inquiry, including science phobia and concerns about grades. In this paper we describe our dilemmas of teaching inquiry in the context of the elementary science methods course and provide potential solutions to these dilemmas.

Inquiry Defined?

Inquiry has played an important role in the reform literature in defining the nature of science and important learning outcomes for students. Scientific inquiry requires the use of evidence, logic, and imagination in developing explanations about the natural world (American Association for the Advancement of Science [AAAS], 1989; 1993). Science students should come to understand what inquiry is, as well as develop the requisite abilities to do inquiry (National Research Council [NRC], 1996). Inquiry is also a pedagogical approach that helps students achieve science understanding "by combining scientific knowledge with reasoning and thinking skills" (NRC, p. 2). When students are engaged in inquiry, they

> Describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations (NRC, p. 2).

Inquiry as a pedagogical approach was further detailed by the publication of an inquiry guide as a supplement to the National Science Education Standards (NRC, 2000), which describes the components of inquiry-based teaching and draws a parallel between scientific and school science inquiry. According to the NRC, learners participating in classroom inquiry (a) are engaged by scientifically oriented questions, (b) give priority to evidence, (c) formulate explanations from evidence, (d) evaluate explanations in light of alternative explanations, and (e) communicate and justify proposed explanations (p. 25).

Researchers and practitioners have described inquiry, conducted studies, and wrote commentaries based on these definitions of inquiry (e.g., Anderson & Speece, 1995; Caton, Brewer, & Brown, 2000; Crawford, 2000; Lederman & Niess, 2000; Luft, 1999; Rossman, 1993). Edelson, Gordin, and Pea (1999) stated that inquiry "involves the pursuit of open-ended questions and is driven by questions generated by the learners" (p. 393), a description that aligns with the science education reform literature.

Others have used modified definitions of inquiry. Allen (1997) described seven different learner tasks at an interactive museum exhibit as "inquiry activities," yet each contained only one or two of the NRC (2000) essential features of inquiry. Some have equated inquiry with the learning cycle. For example, Colburn (Bianchini & Colburn, 2000) described his teaching of the nature of science in a general science course for elementary education majors as inquiry-based and linked to a "three-stage process of exploration, concept introduction, and application" (p. 184). Marshall and Dorward (2000) also described using a form of the learning cycle for inquiry experiences in an introductory college physics course. In their study, students made predictions, developed conceptual models, and expressed the "behavior of the system in their own words" (p. S30). Inquiry has also been described as "giving the students experience with the development of research questions and testable hypotheses" (Stoddart, Abrams, Gasper, & Canaday, 2000, p. 1222).

Keys and Bryan (2001), while agreeing with the NRC description of inquiry, stated that "inquiry is not a specific teaching method or curriculum model" and that "multiple modes and patterns of inquiry-based instruction are not only inevitable but also desirable because they paint a rich picture of meaningful learning in diverse situations" (p. 632). Moreover, Keys and Kennedy (1999) stated the importance of context to inquiry-based learning, including "characteristics of the learners, the school culture, and the science topic" (p. 317). Given that researchers have used varied definitions of inquiry, that also vary by contextual considerations, it is not surprising that science teacher educators struggle when deciding how to teach inquiry in their courses.

Taking their lead from reform documents, textbooks designed for science teacher education contain information on inquiry, and provide methods instructors with a starting point.

For example, Bloom (1998) expanded the 5E model described by Trowbridge and Bybee (1996) to seven stages that contain many of the essential features of inquiry. Furthermore, articles in science publications for teachers, that are included as readings in many methods courses, contain descriptions of inquiry and its implementation to facilitate prospective and in-service teachers in understanding how to teach science using inquiry (Ash & Kluger-Bell, 1999; Colburn, 2000; Kluger-Bell, 1999). Inquiry takes on many meanings in these articles, only some of which are aligned with the standards documents.

Given the complexity of defining and teaching inquiry, researchers have documented some of the challenges of implementing inquiry-based instruction. Elementary teachers lack an understanding of inquiry and do not have the skills or experiences to effectively teach science through inquiry (Crawford, 2000; Lederman & Niess, 2000). Crawford concluded that inquiry-based teaching requires an understanding of the nature of science as well as pedagogical content knowledge. In addition to teachers lacking the necessary skills and knowledge to teach inquiry, Key and Kennedy (1999) discussed an elementary teacher's difficulty balancing inquiry-based instruction with district mandated curriculum and assessment strategies. Edelson, Gordin, and Pea (1999) posited five challenges of implementing inquiry-based learning: motivating students, accessibility of investigation techniques, student background knowledge, student management of extended activities, and learning context constraints.

Although most studies have not directly addressed inquiry in preservice science teacher education, implications for methods course instruction are evident. The purported lack of teacher understanding and skills must be addressed in the methods course. The potential challenges that future teachers face in inquiry teaching must be an explicit part of instruction. However, because inquiry has been defined in multiple ways, facilitating preservice teachers learning and implementation of inquiry in methods courses is complicated. We can learn more by examining how inquiry is taught in elementary science methods, how the students respond, and how improvements can be made.

Context, Questions, and Methods

At various times over the past four years, we have worked as members of a teaching team, planning and enacting a science methods course for future elementary teachers. Through numerous informal conversations about our teaching, we noticed that we shared concerns about the teaching of inquiry in the course. Accordingly, we undertook a more formal examination of how we teach inquiry in elementary science methods based around the following questions: How are we currently teaching inquiry? What aspects of inquiry instruction seem to be working well and what aspects are not working well? What factors influence inquiry instruction in our course? How can we address any identified problems?

The elementary science methods course under study is built on a reflection orientation (Abell & Bryan, 1997) that provides opportunities for students to build theories of science teaching and learning as they: (a) observe others teach, (b) reflect on their own teaching, (c) read expert theories, and (d) examine their own science learning. We have studied this course previously to examine the development of teacher thinking about science teaching and the nature of science (Abell & Bryan, 1997; Abell, Bryan, & Anderson 1998; Abell, Martini, & George, 2001; Abell & Smith, 1994); thus there is a substantial data base from which to work. With the aid of field notes, instructor anecdotal notes, student products, records of team meetings, and course artifacts, we each established lists of issues that related to teaching inquiry in the context of science teacher preparation. In research team meetings, we compared our lists and generated a common set of inquiry teaching dilemmas. In order to represent our collective thinking about teaching inquiry, we generated fictional journal entries based on the data sources, from both teacher and student perspectives. In the next section, we juxtapose these teacher and student narratives in order to exemplify our common teaching dilemmas at three points in time across the course. Finally we present some solutions to the dilemmas.

Presentation of Inquiry Dilemmas Through Journaling

In the following fictional journal entries we have attempted to illustrate the dilemmas that arise when teaching inquiry in an elementary science methods course. The teaching dilemmas arise from a lack of inquiry-based learning experiences for our students and us as well as from our individual constructs of inquiry. The teaching dilemmas include providing sufficient inquiry-based science learning experiences within the limited class and field experience time, balancing modeling inquiry with explicit instruction on inquiry as a pedagogical strategy, and confronting student attitudes toward inquiry, including science phobia and concerns about grades.

Beginning of the Methods Course

During the first class period of our methods course, we often use a short inquiry activity to get students involved, pique their interest, and decrease their anxiety about the course. After that, we introduce a month-long moon inquiry that includes keeping a moon notebook as a graded assignment for the course. During the moon inquiry, students raise questions, record observations, look for patterns, and invent explanations to fit the evidence. We have written elsewhere about this moon inquiry (Abell, George, and Martini, in press; Abell, Martini, and George, 2001; Martini and Abell, 2000) from the perspective of our students' learning about the nature of science and about science teaching. Here we use the context of the extended moon inquiry to help uncover common dilemmas we have faced in teaching inquiry in the methods course.

The Instructor's Journal

1. Well, I jumped right into inquiry in class today. We worked with whirlycopters and students tried to figure out which Whirlycopter flew the "best." Student groups operationally defined "best," selected researchable questions (e.g., What will happen if we use different kinds of paper?), discussed and carried out a research plan, and communicated their results at the Whirlycopter Toy Company board meeting. Short, sweet, to the point. Students enjoyed it and performed confidently. Well, that is all except that group in the back that would not get out of their chairs, even to fly the copters… Why are some students so afraid to "do science"? I wanted them to have some fun and relax a little about taking a course with "science" in the title. I was also aiming for students to understand fair testing and be able to make a fair test plan. I really did not care if they understood any physics principles or if they were thinking about science teaching. I have a feeling that the moon investigation won't be quite so smooth.

2. Today I assigned the moon investigation. We constructed a KWL chart of what they know and want to find out about the moon, and I asked them to observe the moon over the next couple of days and bring their data to class on Thursday. When I said we'd be studying the moon for the next month or so, some students seem surprised, others nervous. If these students are like past students, I can predict that in science class they've seldom, if ever, undertaken a long term inquiry or been asked to reason instead of memorize. Nevertheless, those old doubts about the moon investigation are again creeping into my thoughts. Why do I spend so much of class time on this activity? What are my goals for student learning? Is there a more effective way to achieve these goals in less time? After all, I was not educated this way. OK, let's start at the top. My goals for the students: to learn something about the patterns and explanations for phases of the moon, to feel confident asking scientific questions and using evidence to refine their explanations, to think about how they could use inquiry in their own science teaching.

Well, that's a big set of expectations. Perhaps I am setting myself up for failure immediately. It looks like I have a goal for learning science content, for learning inquiry, and for learning pedagogy. And I realize there are some other goals too—like the goal of getting students to feel more confident about their abilities to think scientifically, which I think will motivate them to teach more science. Maybe that's just too much to accomplish over the coming weeks. Maybe these goals are in competition with each other. On the other hand, maybe they cannot be separated so easily.

3. The moon investigation is in full swing. We have had some very interesting discussions about the patterns we are seeing and the ways we might explain the patterns. This is where I get energy as a teacher—watching students struggle with data, ask interesting questions, and debate their ideas. But will this struggle with science ideas lead to developing their thinking about science teaching? I saw things almost backfire in class today as one frustrated group complained that they were no closer to understanding the moon than they had been two weeks ago. Another group chimed in: "If we can't do this, then surely 5th graders can't." Fortunately there was that group in the back that is really dedicated to their moon study, as they are about everything we have done in the course. They explained how the moon study was a great model for how they could help students build meaning in a powerful way: "I'm beginning to see how my students could learn this stuff in a fun, interactive way." This group also shared some helpful resources they had found about moon phases. The group mentioned how they could use them with a class of elementary students. Did the other groups see this as a way to use the moon journal as a teaching tool? Some of the students seem concerned about how I will grade the moon notebooks, although I thought I had been clear. The assignment sheet specifically states: "You will NOT be evaluated on the scientific accuracy of your ideas, but rather on the

thoughtfulness of your attempts to understand." Yet their worries about getting the "right answer" seem more connected to evaluation than to caring about understanding.

4. Why was the whirlycopters lesson so much easier to carry off than the moon study has been, for both the students and me? Maybe because it only lasted one class period and had specific "steps" in the lesson sequence? My guess is that students will be more successful teaching this sort of short, structured lesson than a long-term inquiry like the moon study. But that worries me. The whirlycopter activity is a good model for fair testing. However, I think it represents inquiry only at a surface feature level: asking questions, making a plan, collecting data, and communicating results (sounds a bit too much like THE scientific method for my liking). The moon investigation, on the other hand, represents inquiry at a deep feature level: that questions, planning, and data collection are all in the service of building explanations of how the world works; argument and evidence are primary. Yet the pedagogy during the moon investigation is more subtle and more demanding of the teacher; I wonder if beginning teachers will be able to carry it off. Well, maybe after a few more examples, like the divers and pendulums, which last more than a single class period but less than a month, I'll see evidence of their increasing understanding. But this sure takes a lot of time. Students also seem to be concerned about the time they spend on the assignment and their grade on the moon journal. We spent some class time going over the rubric for assessing the moon journal. I wish the methods students would trust me on the value of conducting the moon investigation. Would I be better off dropping this modeling and just telling them how to use inquiry-based teaching strategies? But that goes against the whole idea of inquiry-based learning. Argh! Very frustrating!

Student's Journal: Amy

Amy 1. We made and flew our whirly-copters today. I had expected a serious lecture on pressure and how an airplane actually flies and maintains balance in the air and what forces come into play, but instead we played around with paper. I've never done something like this before. It was really hard to think of a question to investigate in this activity. Defining the "best" was not as easy as I had thought. Several of us ended up doing the same thing - what kind of paper makes the best copter. We tried flying our copter, but we did not seem to get any interesting data at all. I think that was because we kept changing the height from which we let our copters go. I tried to tell my group that we needed to use the same height but...This kind of frustrated me and made me not enjoy the activity. I am sure elementary students would love this. However, I am wondering if this activity is appropriate for primary students since it requires being able to make the test fair. I wonder if they can?

A2. Today the instructor introduced the unit on the moon. I got very excited about this unit because this is an area about which I have very little knowledge and I hope to learn more. I thought the KWL chart was cool – we had it last semester in literacy methods. The list of things we wanted to learn was three times longer than the list of what we already knew. I guess the TA will teach us this stuff over the next four weeks. Will it take her that long to get to all the answers? I was surprised when she explained that we were to become "moon watchers" – Sounds weird to me. But I do enjoy looking at the moon!

A3. OK, I've been watching for the moon, but often I can't see it. Clouds cover the sky each time I go out to search for it. One night I went out and it was clear and I still couldn't see the moon. This is really frustrating. Anyway, my group has not seen the moon for some time either. Maybe we just don't know where to look for it. My TA suggested that we look at different times, so we are going to try that. I guess I expected the TA to teach us about the moon so that when we go out there to teach we have somewhere to start from, but she never does. The moon is getting smaller each night, but what does that mean? My partners say it's because the Earth is starting to cover up the moon, so the moon is moving behind the Earth. But I don't think that's it. The shadow can't be covering the moon because we did this ball thing with a yardstick and we saw that the shadow would be from the sun not shining on one side! OK, so I guess I am figuring this out a bit. Maybe this is something I could do in my class, but I still think I would need to give some background information first. Maybe it would be good to assign questions and have kids find the answers in moon books before starting the journal.

A4. I think I'm starting to figure this moon thing out. Comparing the moon models in class today really helped, and my group helped me get it. I am still worried about how I am going to teach this unit to my students especially if they don't write yet. And we've been studying this for 4 weeks. Is it really worth that much time? I guess they could draw the moon and some of their ideas. Or I could do a class journal. Plus, the discussions really helped me and they could do that. I do think I know more about the moon now than when I started. Maybe it is worth the time.

Student's Journal: Brenda

Brenda 1. I'm not exactly sure why, but we're supposed to keep this journal of how class goes this semester and how we think we're growing, etc. I'm pretty sick of reflecting in every ed. course…still, it does seem to help me sort out my thoughts and it's interesting to look back and read. I'm wondering what kind of grade or points we'll get for this thing and if we have to write it in all the time. The first day seemed pretty good. We actually did stuff today like play with these whirlycopter things. It was fun to try and figure out how they worked. We had to write out this experiment thing and include all the directions. That was the hardest part because we realized we weren't very specific. It was so neat because our group did one that no one else did—wing length. Most people did materials. We found that the longer the wing the longer it took to fall, but it spun more slowly. It was nice to be able to get up and move around and talk…it makes the class go faster. I think I would like to do this whirlycopter thing with my students if I teach 4th or 5th grade. I think it can only be used with older students because I don't think that younger students could ask all the questions that we did and be able to investigate them.

B2. We've started these moon journal things and frankly I'm journaled out, plus, we have to draw and stuff. Oh, yeah, I forgot to mention that we started learning about the moon. I like the idea of learning a lot of facts about the moon, but I thought we were supposed to be learning how to teach. So far we just keep doing "stuff." I really am not trying to be picky because class is fun, I just don't know what I'm learning. I'm also wondering how applicable this moon thing will be. How much time do you really need to learn this? We learned about it for maybe 3 days in 5th or 6th grade…it seems like our time could be better spent learning about plants or something. My table did talk about this and one girl brought up the point that maybe the reason we all feel like we don't know anything is because we spent so little time on each topic when we were in school and were overloaded with facts. I think that if a teacher focuses on just a few facts and fun activities, then the students might remember more.

B3. This moon study is really frustrating. I never learn anything in science classes! Actually the journal's not so bad, but today in class we talked forever about the moon and why it looks how it does right now. I was frustrated because so many people were talking and the T.A. didn't really control the discussion. It was like anyone was right and there weren't any answers. She said that's okay right now, but I think I'm going to look up some stuff so I know the correct answers to write in my journal. We're supposed to be asking questions and figuring out answers, but how can I do that if I don't know anything to start? It is really frustrating talking about our data and the patterns, but not figuring out much. This activity would be so frustrating to elementary students. How do you expect the children to stay out at night observing the moon? This is crazy! If I am finding this activity to be very unpleasant, how unpleasant will it be for the children?

B4. Our moon journals are over and I still don't feel like I know a lot of stuff about the moon! We never really talked about the size of the moon or what it is made of even though those questions were in our KWL chart. All I know about the moon now is how it moves and changes. I have no idea about teaching about the moon even after reading those articles. I think younger kids would lose interest doing a moon journal. I think that 4 weeks spent on studying the moon was a waste of time. You don't need so much time on the moon. It was very monotonous doing it every night. I wonder how my TA will grade this activity? I hope she will not expect all the right answers, since our ideas from the KWL chart barely have been tackled. The whirlycopters were much more fun. I'll for sure do them.

Interpreting the Journals

During the beginning of the methods course, we often find ourselves questioning our goals for certain activities and deciding how to best use the time available. The simple whirlycopter activity is typically a success in the eyes of instructors and students alike. Then comes the long-term moon inquiry, where we experience cycles of frustration and illumination. Part of the instructor frustration comes from our own lack of experience with learning school science by inquiry, exacerbated by how we define inquiry and select our course goals. We worry about how to balance our use of course time in service of our goals. Part of our student's frustration and apprehension comes from their lack of experience with inquiry-based science, and with their own expectations for both how science should be taught and what the methods course should be about. Another source of student frustration is their self-perceived lack of science content knowledge, which begins to generate grade anxiety. They appreciate the active class periods, but wonder if they are learning science or teaching strategies, and worry about how they will be graded. These dilemmas persist into the middle of the methods course, where new dilemmas also arise.

Middle of the Methods Course

Once the moon inquiry ends, we expect students to accelerate their transition from a student perspective on inquiry to thinking like a teacher. In a 2-day Cartesian divers inquiry, students develop and test their own investigation questions as they try to figure out how the divers work. They examine how teachers can scaffold such an experience for students. Then, in a 3-day pendulum inquiry that is based on a learning cycle approach, students see how to put together many inquiry-based teaching strategies into a coherent learning sequence for students. By the end of this sequence, we expect students to start planning their own science lessons for elementary students in a partner school. Our journals tell a typical story for this part of the course.

The Instructor's Journal

1. This week we used a Cartesian divers inquiry to model how teachers can scaffold student-directed inquiry in their classrooms. When students saw the diver sink as the bottle was squeezed, they asked, "Why does it do that?" Rather than provide an answer, we demonstrated a process of defining and selecting testable questions (e.g., What would happen if we used different liquids in the diver?) and required them to write an investigation plan. Teams carried out their plan and shared the results. But what makes divers different from the whirlycopters? I think it's because, once the findings were in, we returned to the "Why" question and tried to relate what we found out about the divers to what we knew about sinking and floating, and developed viable explanations for the diver behavior. Of course, this also made the divers

inquiry more frustrating for the students. Their understanding of sinking and floating is pretty shaky. Feelings of science inadequacy resurfaced within several groups. So now I'm back to my old worries. Is my job to help them learn the science or just the pedagogy? Can I do the latter without the former? But do I have time to do both? During the last class period, I chose to not complete all the parts of the divers activity as I would with elementary students, opting instead for, "If you were my fifth graders, we'd now take some time to..." Is this a cop out, or can students fit this into their inquiry teaching/learning scheme? Making decisions about what to cut out when time runs short is a continuing dilemma for me, especially when I want to focus on pedagogy yet they seem to need more science content.

2. With the completion of the Cartesian diver activity, we moved on to a 3-day pendulum inquiry, where students try to figure out the fastest way to get Tarzan across a canyon—using a short or long vine, with or without trusted friend Cheetah. My goals for this activity are to engage students with inquiry into the pendulum phenomenon and to introduce them to the Learning Cycle as a model of inquiry-based instruction. Since the students are going to develop and teach their own 3-day Learning Cycle unit, I want to model it for them in class. Again I face the dilemma of using so much class time for inquiry, but in this case I think it is time well spent. The amazing thing was that the talk in each group picked up while they were constructing their experimental set-ups. They were posing their own explanations and trying out various ideas. They may be finally past their fear of science; at least everyone was active! But now I wonder if my modeling will help them understand the Learning Cycle. Sometimes I think my goal of making sense of pendulums pre-empts their learning about pedagogy.

3. Today in class one group was insistent that the angle of Tarzan's vine affected the performance of the pendulum. I threw it open for discussion. All the while I worried about the time this was taking and doubted my own understanding of the concept. I reached temporary

closure by agreeing to look up some information and get back to them next class. I really thought it was important to take time to analyze what we had done in terms of the Learning Cycle. Their inquiry lesson plan first draft is due next week and the class had many questions about what to include in their lesson plans. I'm hoping they can translate all we have done, discussed, and read about into viable lessons.

Student's Journal: Amy

A1. Today it was fun to do the divers with 2-liter bottles. We were on our feet most of the time and talking and discussing our ideas. I was surprised that when you squeeze the bottle, the dropper inside of it plunges to the bottom of the bottle, but when you release the bottle, the dropper quickly shoots up to the surface. What's the trick? Why does this happen? We talked about why this happened and thought that it may be due to the pressure (air) or the weight and gravity? Or may be the water inside of the dropper was lighter? Our test was to change the color of the water in the diver. We could then easily see that when we pushed the bottle, the water came out of the dropper. It was fun when all the groups got together to discuss their findings. It was like putting a puzzle together-little by little we saw this picture of the diver sinking and floating and we decided that weight (or what someone called density) was a factor. What we did was just like what we read about in the chapter about planning an investigation. The readings are starting to connect to the course and help me understand why we're doing what we're doing.

A2. Today we brainstormed the factors that can affect the pendulum. I had an idea of how pendulums are applied in clocks because of the grandfather clock that I grew up watching. I think elementary students will enjoy this activity too. It was interesting making our predictions and designing and carrying out the investigation to test them. But the most difficult thing was to determine what a swing was, when to begin counting and timing, and eventually drawing graphs. One girl in our team, who took physics 151 last semester, yelled, "Why don't you give us the instructions? How do you expect us to know what to look for in our investigation?" In Physics 151, she was my lab partner and we did a similar activity, but I remember we were given a list of instructions and a worksheet to follow and that made it pretty simple and we obtained more accurate results. I like this better, even if she doesn't. I feel like I understand so much more because I have to figure it out for myself. I'm worried about the lesson plan we are supposed to start writing. I'm having fun with these activities and think I can use this stuff with kids, but I'm not quite sure how to organize it.

A3. Today we continued working on this Tarzan problem. We really are learning about pendulums, but I think that the T.A. used the Tarzan story to make it more interesting. We got to use all this stuff and set it up to figure out the answers. We found out that he went a lot faster if he used the short vine. That really didn't surprise me, but the cool part was that it didn't matter whether we added a ton of weight or not! It still went the same! Not what I predicted! One group set up their experiment more like the picture or something, but they got a lot of different data. It was so funny because this guy kept arguing with the T.A. that the angle of the vine mattered and that's why it worked that way. I didn't get everything they were talking about, so I didn't get involved, but it was interesting to listen. She asked what we would do as teachers if someone got different results. At first, I thought I would just say that all the other groups got the same answer, so he must have a problem. Our TA didn't seem to do that though…she just let it ride. So now I am thinking I would too, but I would want the students to try to figure out why the results were different. I did figure something out today, though my TA showed us how the pendulum activity was like the Learning Cycle that we read about. I get it! In our units, we can start by exploring, and then come with some kind of application. I may not understand everything about pendulums, but I do think I get this Learning Cycle business.

Student's Journal: Brenda

B1. In this 2-liter bottle thing, if you squeeze the bottle, the dropper inside sinks and if you let go, it floats. I have no idea why, but this guy in my group said that it's air pressure. I think the answer to everything is air pressure to him. It was fun because we got to try and figure out why it did that. My group is going to try to figure out how it works if you use three droppers with different amounts of liquid in each. Of course we have Mr. Smartie in our group, and he said all of this stuff about density and pressure. But I still don't get it. I wish we'd get it right and learn something or at least have the T.A. teach us it.

B2. We spent almost the whole class again working on our investigations! I'm freaking out because we have not heard anything about this lesson we're supposed to teach in like 2 weeks! We don't have a rubric and the thing in the syllabus doesn't seem to explain exactly what we're supposed to do. I understand we're supposed to be getting good ideas by doing all this stuff in class, and it is fun, but shouldn't we start learning about how to teach science?? I don't think we've really done a lot of that, I mean, we talk about the articles we read, but she doesn't really make us take notes or anything (not that I care) and we don't really have examples of how to do this. They really haven't given us a set way to write a lesson plan, and I'm getting a little worried. My whole group is worried. And Tarzan! How lame! Plus everyone knows weight matters.

B3. We continued the pendulum study today, the activity part was fun. My group tested length and weight. I think it's interesting they both changed how the vine worked. I knew it! He better leave Cheetah behind! At first we got the same results for the different weights, but I knew we were wrong so we fixed it. I couldn't believe how John kept arguing with the T.A. and she didn't know if he was right or not. We finally went over the next assignment. I think teaching this cycle thing will be fun. There are lots of fun activities I know about from this great teacher website. Can't wait to do some of them with the students.

Interpreting the Journals

By the middle of the course, we often notice that student's fear of doing science begins to wane. We see them becoming a bit more confident with doing inquiry, and some even recognize that they can generate viable explanations based on the evidence from their investigations. The students also begin to see the pedagogical side to teaching inquiry but it is still frustrating for them.

Our concerns about how to best use class time are exacerbated as our priorities shift. At this point in the course, we have a primary objective of preparing students for their field-based teaching that takes place concurrently with the methods course. The pressure to help students understand inquiry-based pedagogy is great. It takes astute students to see how our modeling can be applied to their future teaching, and we always feel the need to spend more time explicitly addressing pedagogical issues. The time issue persists throughout the entire course right up to the time when the methods students plan and implement their 3-day science units.

End of the Methods Course

By the last third of the course, the priority becomes preparing for teaching a 3-day lesson sequence in a partner school. With input from their cooperating teacher and course instructor, teaching teams select a topic, develop learning goals, and create learning and assessment activities. In addition to curriculum design, most groups spend some time making sense of the science they are preparing to teach. In the field they team-teach and individually reflect on their teaching and student learning, with feedback from the cooperating teacher and the course instructor.

The Instructor's Journal.

1. Today in class groups worked on the inquiry-based lessons they will be teaching next week. Plus, it is only two weeks until they teach their learning cycle lessons. Where does the time go? For the learning cycle, one team wants to plan lessons on volcanoes for their second grade class. They think volcanoes will be "fun." I am so sick of that word! Just because a model of a volcano explodes and the elementary students think it is fun does not mean that it is inquiry-based science. Some topics are more conducive to engaging students with phenomena and allowing them to develop explanations. The state standards for the second grade require students to investigate weather, the patterns in seasons, and examine earth materials. Volcanoes are not even mentioned. Another issue came up near the end of the class period while we were going over the Learning Cycle assignment. Some students feel they did not have enough opportunities to understand inquiry-based instruction this semester. They are also concerned about how that lack of experience will translate into their grade for the final science unit. I thought that by using Cartesian divers, pendulums, whirlycopters, and the moon investigation that inquiry-based teaching was being modeled. I think they were focusing too much on the science and not enough on the pedagogy. How can I fix this? What else could I do to provide a more complete picture of classroom inquiry? How can I address the concern they have about their grades?

2. I held unit plan conferences today during class time. That one group still wants to present a unit on volcanoes using an activity they found on the Web. The cooperating teacher in their field experience classroom has a volcano chapter in the science textbook and encouraged them to pursue the activity. The students were well prepared with a copy of the lesson plan and the book borrowed from the classroom teacher. I repeated my concern that their lesson was not inquiry-based: it did not engage students with scientifically oriented questions or give the students an opportunity to give priority to evidence in developing explanations. I asked them where their unit was hands-on, minds-on, and engaged the children with phenomena. I then

asked them what standards support the teaching of volcanoes in a second grade lesson. I'm not sure how volcanoes could be taught in an inquiry-based manner, but they are definitely NOT doing it. I don't know if I have the expertise to figure it out, how will they? After the unit plan conference, a member of the volcano group emailed me to say they were changing their unit topic to erosion and that it was all right with the cooperating teacher. I am eager to see what they come up with. I think they're mad at me but just gave in to get the grade. I hope after all is said and done, they learn something about the difference between planning lessons and planning inquiry lessons.

3. The students are teaching their inquiry lessons this week at the field experience site. I went to the school site to observe them. The erosion group started with a KWL chart to find out what students knew; they got some really good questions from their second grade students. Then they got the stream tables going and students explored what happened with different amounts of water. The teaching group seemed pleased with the interest level in the class and the degree to which students actually talked about their ideas. Maybe inquiry is starting to make more sense to them.

Student's Journal: Amy

A1. Today we looked at some lessons. I was surprised planning a lesson is so demanding. Objectives need to be clearly stated and achievable; a lesson should have all the necessary concepts and activities, methods and assessment strategies. I guess with time, I will develop the skill. But it is tough making these lessons inquiry based. I hope this pays off.

A2. We began teaching our inquiry lessons today. Children were knowledgeable about swings and were very eager to do the activity. We identified factors that affect the swing of a pendulum and children began their investigations. Children had a problem in counting the number of swings. However, because we spent a lot of time in planning, we did not finish the activities we had planned to do for the day. It was frustrating that we did not achieve our objectives for the day. The teacher said she would let the students finish tomorrow so when we come back they'll be ready. We met with the T.A. about our learning cycle lessons. She really likes our magnet lessons and thinks we did a great job planning. I hope the students like it!

A3. Our learning cycle lessons on magnets went well. The kids had a lot of fun playing with the magnets the first day and figuring what sticks and what doesn't. I think they figured out that it wasn't just metal, but certain kinds of metal. I was surprised at how they figured stuff out. It was kinda cool to hear them talking to each other about why they thought stuff, but it was crazy to have them all talking at once. But the discussion helped so many of the students understand, so I would do it again. The journals we had them do didn't work very well. They ended up being too hard to manage. I think we could have done better if we just had them talk about what they thought, but then it's hard to get individual ideas. But the journals just took too much time. Yet, I know it's important for them to use these to work out and express their ideas. Maybe the problem was our limited teaching time? I bet this will work when I have my own class if I simplify the journals a little. This is the last week to write in our journals. I think that I've learned a lot this semester. I have a lot of good stuff to do with my students like our moon journal, electricity stuff, Tarzan, magnets and sink and float stuff. If I get a job teaching younger grades, I know I won't have as much time to teach science, but at least I have some ideas about science stuff to do that isn't just textbook and vocabulary.

Student's Journal: Brenda

B1. Ok…we went over the lesson plan stuff today, and are starting to design our first inquiry lesson. But why do we have to do all this? The lesson plan was like 100 pages long. Will I ever do this when I am teaching? I don't think it is necessary to have everything in the lesson.

My group is okay. For our learning cycle unit, we're supposed to teach about earth science, and I want to do some real fun activity because we are working with second grade. I'm not sure that they are able to do much, but if we find a fun activity, then they would be more focused. Again the T.A. said we have to do activities that really make them think. That's why I think it is a good idea to do volcanoes and have the kids make volcanoes that blow up. We did that in school and I still remember it.

B2. We had our meeting with the T.A. today about our unit plans. Afterwards, my volcano idea was vetoed by my group. I know that we're supposed to do this "inquiry" thing with productive questions, but I'm really not sure how practical it is. My teacher at the elementary school really liked the idea of volcanoes, and I'm a little upset that my T.A. can say that it won't work and then the group agrees. I still don't really get why, our lesson was fine and we had inquiry questions. I think that the kids would do a lot of thinking about how volcanoes work, and I know they would be interested. And if they're doing science aren't they learning it? That's all I'm going to write today.

B3. We taught our unit lessons on Earth science. We did a lesson on erosion. It was fun! The kids used big stream tables to figure out what would happen as we poured water down each one. We did the pouring, but it was fun to see the kids get so excited about having their predictions work out! Kids asked a lot of questions whose answers I didn't know. I was just not prepared. Next time I teach this I would be better prepared to answer their questions and we wouldn't have to do so many investigations. Maybe you could do a whole unit on Earth science and erosion, earthquakes, volcanoes, etc. Then I could get my volcano lesson in! No more journals!

Interpreting the Journals

As students make their final transition from thinking about inquiry as students to thinking like teachers, their constructions of inquiry come to the forefront. We discover how effective/ineffective we have been at modeling inquiry and at helping students understand inquiry-based pedagogical strategies. Sometimes we are disheartened by students who change their lessons only to please us. We know once they leave our course, they will switch back to viewing activities such as making a volcano model as inquiry. Other students amaze us by the degree to which they have internalized what it means to learn and to teach science through inquiry. These students have the potential to change the way science is taught in elementary schools. By the end of the course, we are left with our own dilemmas of how to balance our use of class time as we balance our learning goals for both science content and science pedagogy. These dilemmas of student learning and our own teaching push us to reconsider our teaching for the next time we offer the course.

Discussion

Through our team meeting discussions, we established seven dilemmas of teaching inquiry in the methods course: varying definitions of inquiry, our struggle to provide sufficient inquiry-based science learning experiences, perceived time constraints, determining how much of our course should be slated for science instruction versus pedagogy instruction, instructors' and students' lack of inquiry-based learning experiences, grade versus trust issues with our students, and our students' science-phobia. In the following section, we summarize dilemmas and discuss how we have attempted to deal with them within our elementary methods course.

Varying Definitions of Inquiry

The definition of inquiry is dynamic and context dependent. Moreover, if one frames inquiry within a constructivist paradigm in which reality is a socially and experientially constructed entity and its form and content depend on those who hold the construction (Lincoln & Guba, 2000; Schwandt, 1997; 2000; von Glasersfeld, 1996), then a larger dilemma looms. Each instructor and each student will construct his or her own working definition of inquiry. While certain components of inquiry appear common to the instructors, this dilemma loomed large for the students and provided them ammunition for dismissing inquiry as valid in science teaching and learning. In addition to lack of agreement in the literature, each instructor of the course teaches using his or her own working definition of inquiry. Some of us are comfortable with a learning cycle model of inquiry, others prefer a standards based model of inquiry, and others see little difference between the two. Members of the team have held lengthy discussions about the importance of certain inquiry components, such as the need for student developed investigation questions. Ultimately, for each of us, there are components of inquiry that are nonnegotiable and others that vary in importance based on the context of instruction.

We have addressed this issue via multiple routes. The first solution was to provide the students multiple readings on inquiry, including sections of the standards (Ash & Kluger-Bell, 1999; Bloom, 2000; Colburn, 2000; Kluger-Bell, 1999; NRC, 1996; 2000; Whitin, 1997). These readings and ensuing class discussions allow the students to examine multiple perspectives on inquiry and often help them planning lessons because they can determine which stance they feel most comfortable using. In addition to science talks (Gallas, 1995; Lemke, 1990), we hold pedagogy talks. These provide the students opportunities to develop an understanding of inquiry-based pedagogy in a similar social framework to the talks in which they develop and express much of their science understanding. These thought provoking discussions are often linked to reflections that students write expressing their ideas on inquiry based lessons. These reflections help the students construct a personal working definition of inquiry. Another route for addressing this problem is through lessons on the nature of science. Using black box activities, demonstrations, articles, and discussions, we expose the students to multiple aspects of the nature of science, including the idea that science is done through many different approaches. By helping the students realize this, we are able to utilize an analogy for inquiry based instruction: If there is more than one way to do science, the can be more than one way to do inquiry.

Sufficient Inquiry-Based Science Learning Experiences, Time Constraints, Science Instruction Versus Pedagogy Instruction

These three issues are so intertwined that they require simultaneous consideration. As instructors, we feel an obligation to provide time in our course for inquiry-based science learning; yet, the focal point of the course is not science instruction. Moreover, it would be impossible to provide the students multiple extensive experiences with inquiry based learning in a one-semester methods course. Analogously, the students cannot teach multiple extensive inquiry lessons during their field experience component. Because our students' lack of experience with inquiry and desire to learn more science, we slate several weeks of the course for modeling the teaching of inquiry-based science. Yet, we struggle with what the focal point of those weeks should be, pedagogy or science. A conundrum develops: how do we teach the pedagogy if students do not understand the science, but how do we teach the science if they do not understand the pedagogy? In other words, we cannot be successful teaching the pedagogy through modeling, because students get so wrapped in the student-based perspective of science learning that they miss the pedagogy. On the other hand, if we try to teach them science through inquiry based methods and they do not understand the methods, they often feel they have learned no science because they have not memorized facts and taken tests.

One of the most significant changes to our course is that we have increased the amount of time devoted to field experiences without decreasing on campus time. A separate field experience time is scheduled as part of a block of classes, including literacy and math methods. This system allows us more class time to conduct investigations with our students and discuss the related pedagogy. This also provides the students more time with children and more flexible teaching schedules; if their lessons do not progress as originally planned, they can make adjustments changes for the next field experience time.

We also model inquiry at multiples levels and in stages. For example, the whirlycopter activity introduces students to the idea of planning and carrying out investigations while the Cartesian divers provides a more intense inquiry experience. The moon study demonstrates an extended inquiry with a strong focus on explanation and evidence. The pendulum provides an example of a lesson sequence template that can be used in their own plans for elementary students. Finally, we have made concerted efforts to be more explicit about the pedagogy while teaching all inquiry lessons.

Instructor's and Students' Lack of Inquiry-Based Learning Experiences

We, the methods instructors, did not learn school science through inquiry. This lack of experience raised the dilemma: Can teachers not taught using inquiry effectively teach using inquiry? Fortunately, the instructors have had adult experiences learning science through inquiry. Some of us have had summer experiences with companies conducting science research, some have participated in National Science Foundation teacher institutes research programs, and some have had graduate level experiences with science research. Thus, although we were not educated in schools via inquiry methods, we have adult inquiry-based learning experiences and thus feel somewhat comfortable teaching other adults science in a similar manner.

However, most of our students have little or no experience learning science through inquiry. This problem connects to the dilemmas of time and pedagogy vs. science recounted earlier. It is obvious that we must provide inquiry-based learning opportunities as described above. However, there is another underlying problem: our students often view inquiry lessons as weak and lacking science content because they cannot always identify what science concepts are learned from the experience. To help address this problem, we have the methods students write final reflections after some of the inquiry experiences to help them connect content learning to inquiry-based learning. We also require our students to include science content learning objectives and a detailed explanation of their understanding of the science content in their lesson plans. This helps them to connect, from a teacher's perspective, science content with inquiry-based instruction.

Grades Versus Trust Issues and Science-Phobia

Having been taught science in the positivistic frame of "right" answers and objective testing, our students do not trust us when we ask them to write and teach inquiry-based lessons. They worry that their grades will be affected negatively by their lack of science content knowledge. They struggle to find a balance between providing facts for their students and providing opportunities for the students to make sense of concepts through investigations. Moreover, because they have no reference frame from which to work, our students want to know "what I have to do to get an A in this course" and struggle when their own investigations do not provide what they view as the "correct answers." They get upset with instructors who do not tell or confirm the right answer. Accordingly, the assessment component of their lessons often involves participation and no assessment of content knowledge.

This problem is compounded by their science-phobia. Many students enter the methods course with a fear of and disdain for science. When we teach using inquiry, they are further removed from their educational comfort zone and thus often express that they "cannot learn science this way." They want to know what facts to memorize and then take a quiz. Addressing our students' science-phobia is difficult, but important, in a methods course.

In the syllabus, we now include grading rubrics with all major assignments. Many of us ask the students to evaluate themselves prior to turning in the assignment to help them understand our grading policies. We have also created a sample lesson plan that the students evaluate as a homework assignment early in the course. This has greatly reduced the students stress about the first major grade in our course. We have added statements regarding evaluation to the moon unit. In those statements we stress the importance of using evidence to substantiate their points and showing progress in understanding as opposed to stressing "correct" understanding of the moon processes. Additionally, this helps alleviate some of the science-phobia issues because they no longer need that "correct" answer to be successful. The early classroom experiences, such as the whirlycopters, can also lessen science-phobia because the students are successful from the start.

Conclusion

Understanding what happens in a science methods course is an important step in creating a successful teacher education program. If we expect our students to teach inquiry-based science, we need to examine how we teach inquiry. The work reported here leads to research -on understanding how students perceive challenges to teaching inquiry and how they make the transition from the method course to student teaching and beyond in terms of inquiry-based instruction. And most importantly, the opportunity for us to work as a team to consider and reconsider our teaching of inquiry has been critical to our development as science teacher educators.

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GETTING TO THE FOURTH YEAR: PRELIMINARY FINDINGS REGARDING THE PRACTICE OF MN BEGINNING K-12 SCIENCE TEACHERS.

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Since 1993, the state of Minnesota has been involved in "the process of transforming teacher education in mathematics and science so that teachers will be prepared to teach according to the vision of present and future national standards and will be prepared to continue learning new content and new ways of teaching throughout their professional lives (SciMath^{MN}, undated). SciMath^{MN}, publicly-funded statewide coalition for mathematics and science education, had led the way. To accomplish this mission, SciMath^{MN} formed a statewide collaborative called Transforming Teacher Education (TTE) between policymakers, universities and school districts interested in improving teacher education. Since its inception, TTE has been working to make recommendations that shaped new teacher licensure rules, providing professional development programs for all involved in teacher education, and awarding small grants to support individual campus initiatives that aim to change education programs and courses for K-12 science and mathematics teachers. In the early 1990's, a document entitled *Transforming Teacher Education: A Minnesota Framework for Teacher Education* was developed that provides standards for what beginning teachers in Minnesota should know and be able to do (Simpson and Wallace, undated). This TTE framework document provides a powerful lens through which to engage in teacher education and has played a significant role in this research project.

Purpose of the Teacher Research Network

As a logical next step in the process of transforming teacher education, the Teacher Research Network (TRN) was formed in 1998. TRN, which includes individuals from public and private teacher preparation institutions, was developed to assess the knowledge and practice of Minnesota's beginning teachers as defined by individuals in their first three years of practice. The research project is now in its third year. Information on the structure and implementation of the organization has been presented at a previous AETS meeting (Simpson, Shume, Davis, Cline, & Tonnis, 2001). Funding for this research was provided for by SciMath^{MN}.

TRN initially attempted to determine the extent to which beginning science and mathematics teachers' beliefs and practices aligned with state and national standards using instruments developed primarily for the Salish Project[2]. Usage of these instruments in the TRN project required modification of them to align with our research questions, which examine the five major components of the TTE framework: science content knowledge, pedagogical knowledge, knowledge of students, establishing a learning environment, and developing as a teacher (Simpson and Wallace, undated). A final research question relates to the status and context of Minnesota's beginning teachers.

Instrumentation and Data Collection

A number of instruments are used to address these questions through the lenses of the teacher participants, the student participants, and the researchers. A teacher's perspective is presented through completion of the teacher version of the Constructivist Learning Environment Survey 2(20) (CLES2 (20)), the Science Teacher Self Efficacy Beliefs Inventory Form B (STEBI), pre and post observation questionnaires, and an interview. The students' perspective is collected with the student's version of CLES2 (20). Information about the context of the research is supplemented by teacher and researcher demographic questionnaires. The researcher's perspective comes from the observations made of two lessons using the Minnesota Science Teacher Observation Instrument (MNSTOI) and their synthesis of all three perspectives into a summary document called a teacher profile. Individual teacher profiles serve as the basis for further data analysis.

The survey instruments are administered first. Every teacher and his/her students complete the CLES2 (20) survey; two versions are used, one for teachers and one for students. The original CLES instrument was developed in Australia "to enable teacher-researchers to monitor their development of constructivist approaches to teaching school science." (Taylor, Dawson & Fraser, 1995, p1). The CLES2(20) version, a modification of the original CLES, has the same purpose but was shortened and modified for use with younger students (Johnson, 2002). Teachers then complete the STEBI survey designed to measure teacher beliefs about their ability to make a difference with students (Enochs, 1996). The teacher completes a demographic questionnaire describing his/her school, course, classroom and students. Researchers complete a separate demographics questionnaire describing their university, role at the university, any prior experiences interacting with the teacher participating in this study (such as university courses or field supervision) and their general educational background and experiences with teaching and teacher education. Thus, the survey data collected includes CLES2(20) surveys from teachers and students, STEBI surveys from teachers, and demographics questionnaires from teachers and researchers.

Once survey data has been collected, the next instrument administered is the Minnesota Science Teacher Observation Instrument (MNSTOI) which serves as a guide for teacher observations. This instrument organizes the observation process around five characteristics of quality teacher preparation identified by the TTE framework (Simpson and Wallace, undated). Each characteristic includes a series of specific prompts to guide the researcher's observations. These prompts are meant to ensure that every researcher examines a teacher in as similar a manner as possible. The prompts were modified from the assessment guide developed for the Interstate New Teacher Assessment and Support Consortium (INTASC) portfolio project (Collins, 2002). The MNSTOI is comprised of a pre-observation questionnaire describing the teacher's plan for the lesson, the observation form itself, and a post-observation questionnaire providing the teacher's reflections on the success of the lesson and makes suggestions for further instruction. The two lessons observed are selected by the teacher, who is asked to choose one lesson that develops a science concept and another that represents inquiry (as he or she defines it.)

Finally, teachers complete an extensive audiotaped interview based on the Minnesota Science Teacher Interview Instrument (MNSTII). This instrument was modified from the Salish project's Teacher Pedagogical Philosophy Inventory (TPPI) to align with our research questions and consequently the standards for new teachers in Minnesota described in the TTE framework (Simpson and Wallace, undated). The fifteen questions and associated prompts are designed to result in a guided discussion between the researcher and the teacher. A detailed presentation on these instruments and their analysis was presented at a separate session of this 2002 AETS meeting (Davis, Simpson, Johnson, & Wallace, 2002).

Data Analysis

Data for the study was divided into two groups based on the grade level of the student participants: elementary (grades 3[3]-6) or secondary (grades 7-12). For each group, two levels of analysis were undertaken. The initial analysis was conducted by individual researchers who triangulated data from the CLES2(20) student surveys, the CLES2(20) teacher survey, the teacher's STEBI survey, two classroom observations using the MNSTOI, and the MNSTII interview transcript. This initial analysis resulted in a narrative teacher profile, a snapshot of that teacher's beliefs and practices.

A common profile template developed by the TRN was divided into the following areas: context, knowing science content, knowing pedagogy, knowing students, establishing a learning environment, developing as a teacher, and researcher comments. Like our research questions and our MNSTII interview questions, these categories reflect the organization of the standards for new science teachers in Minnesota described in the TTE framework (Simpson and Wallace, undated).

After the first level of analysis, two groups of profiles had been created, one set of elementary teacher profiles and one set of secondary teacher profiles. Each group of profiles then underwent a second level of analysis that aimed to identify similarities and differences, patterns that emerged, and any conspicuous absences. In addition, further directions for research were identified as were any concerns pertaining to the data collection procedures and/or the creation of the profiles. The elementary and secondary draft reports were prepared by analysts who also served as researchers in the TRN. These drafts were each reviewed by two other TRN researchers and subsequently revised by the original analysts.

Dori Tonnis prepared the initial draft and final report of the elementary profiles analysis with Tom Tommet serving as reviewer. Teresa Shume prepared the initial draft and final report of the secondary profiles analysis with Cathy Summa and Lynn Hartshorn serving as reviewers.

A list of Teacher Research Network researchers involved in instrument design and data collection appears at the end of this paper.

Organization of Findings

An attempt to describe the findings related to each of project's research questions is beyond the scope of this paper. Therefore, the authors have chosen to focus on the data collected about the research question, "What do Minnesota beginning teachers know about pedagogy?". In order to help the reader understand our results, the following provides a brief overview of how pedagogy was defined for the purpose of this investigation.

The TTE framework states, "Several essential components serve as lenses through which teachers filter their knowledge of the discipline in order to make effective decisions about teaching. Mastery of pedagogy enables teachers to transform content knowledge into powerful and productive learning experiences that are appropriate for diverse groups of students" (Simpson and Wallace, undated, p26). In this document, the knowledge base for pedagogy is divided into six categories that describe the knowledge and skills of beginning teachers who demonstrate mastery of pedagogy. In particular, beginning teachers will "develop a rationale for making decisions about instruction; know and use instructional resources, know and use instructional strategies; know and use strategies to promote discourse and foster a learning community; know and use means to assess student understanding; and, understand and use pedagogical content knowledge" (Simpson and Wallace, undated, p 26). Clarification of each of these six categories can be found in the TTE framework available on line at the SciMath^{MN} web site.

For each group of profiles, our findings begin with a synopsis of the contexts describing details about the teachers participating in the study, their assignments, and the schools in which they teach. The findings for the "knowing pedagogy" research question are divided into six sections: kinds of activities, appropriateness of activities, kinds of thinking used/classroom discourse, teacher's role in class and discourse, assessment, and external resources. These sections are congruent with the organization of the corresponding section of (INTASC) portfolio project (Collins, 2002) and reflect the essence of the TTE framework (Simpson and Wallace, undated).

Findings from the Elementary Group

Context

Seven teachers held undergraduate degrees in elementary education (Ms. Christianson, Ms. Brandon*, Ms. Kelly, Ms. Vee*, Ms. Cam*, Ms. Kantor*, Mr. Beane*), one teacher had a fifth year certification (Mr. Mattr) and one teacher held a MAT degree in elementary education (Mr. Goodman*). The six teachers designated with an asterisk were in their first year of teaching, and three others were in their second year. Five teachers were participating for their first time in the TRN study, while Ms. Christianson and Ms. Vee had participated the year before as well. Mr. Mattr was in his third year, participating since the inception of TRN.

Twelve elementary teachers participated in this year's study, however profiles were written for only nine of them. The teachers taught in a wide range of learning environments which included public, private, charter, rural, urban, and suburban schools in Minnesota. Some were K-5 schools, one was K-8 and another was K-9. While most taught at regular public schools, three worked at private schools and two were employed by charter schools. One charter school was designed to meet the needs of Native American students while the other provided a learning environment for Asian/Hmong students.

Seven of the teachers obtained undergraduate degrees and licenses in elementary teaching. Of those teachers, six also had a math/science co-major that provided them with a greater number of learning experiences in the sciences and mathematics. One of the remaining two teachers earned a teaching license through a fifth year program and majored in Physical Geography in his undergraduate studies. The final teacher in the study earned a MAT degree in elementary education and had an undergraduate degree in Environmental Policy Studies.

Six of the teachers were generalists, teaching all subjects to their students. One teacher taught science to all 4th grade students in her school, as well as language arts and social studies to one class of students. One teacher had science and social studies responsibilities for the fifth grade students in his school. One teacher taught uniquely science, provide science instruction for students kindergarten through 5th grade at his school.

The contexts of two teachers are worthy of particular note. One first year teacher, Ms. Vee, was a non-traditional undergraduate student who earned her GED in her mid-twenties, and went to college in her thirties. She had a significant learning disability and taught students grades 3-6 in a self-contained, special education class at a Native American charter school in an urban setting. There was no expectation for students in this class to be taught science. The second profile of note, Mr. Mattr, was a second year teacher who had four years of teaching experience prior to obtaining his fifth year teaching license. The backgrounds of these two teachers were substantially different than those of the other teachers who participated in this year's study. A summary of the context information is presented in Table 1.

Table 1

Summary of Contexts of Elementary Science Teachers

Pseudonym	Year of Experience	Subject(s) Taught	Grade Taught	School Type	Gender

Ms. Christianson	2nd	generalist	5th	public, K-5, suburban	female
Ms. Brandon	1st	science	4th	private, suburban	female
Mr. Mattr	2nd*	science, social studies	4th	public, rural	male
Ms. Kelly	2nd	generalist	3rd	public, urban	female
Ms. Yee	1st	generalist	3rd-6th	public, urban, charter	female
Ms. Cam	1st	generalist	3rd	public, urban charter	female
Ms. Kantor	1st	generalist	5th	private, urban	female
Mr. Goodman	1st	generalist	3rd-4th	public, urban/suburban**	male
Mr. Beane	1st	science	K-5th	private, urban	male

Note:
* Although only in his second year of licensed classroom teaching, Mr. Mattr taught for four years prior to becoming certified.

** This school serves an urban district as well as nine surrounding districts, including suburban ones.

Kinds of Science Activities

Seven of the nine elementary science teachers used the Full Options Science System (FOSS) kits as their science curriculum. One of these seven teachers included AIMS lessons in her curriculum. The topics of FOSS units selected by teachers included galaxies and stars, rocks and minerals, inventions, pulleys and levers, and sound. Ms. Vee and Mr. Mattr, on the other hand, designed their own science curricula. Ms. Vee developed units on topics including oceans and habits, as well as forestry and conservation, while Mr. Mattr developed a unit on plants and plant growth.

Ms. Christianson defined "activity" this way, "Every time they [the students] do something with another person I feel is an activity." Others used the term 'hands-on' to describe science activities. To Ms. Kelly the term "activity" meant, "Some kind of 'hands-on, kinesthetic activity' requiring students to do some thinking and figuring some things out…trying to get the whole picture before you make your final statement." It was apparent from the data that these new teachers held a strong belief about students being involved in active science learning. The MNSTOI observation instrument provided a guiding lens for two classroom observations, one designated an inquiry lesson by the teacher and the other identified as a lesson intending to develop a concept. However, teachers identified nearly all lessons as inquiry lessons because FOSS kits were used.

Activities observed by researchers included small and large group discussions, hands-on lessons, experiments, a PowerPoint review game, construction of products, and development of a project. Teachers selected units and activities for a variety of reasons. The unit selection for some was based upon the district's or school's designation of FOSS kit used for each grade level. One teacher, Ms. Brandon, selected the FOSS units by finding out what kits were used in the previous and subsequent grade levels. Mr. Goodman, on the other hand, selected the FOSS Kits based upon availability. Evidence from the MNSTOI and interviews suggested that teachers selected activities from the units to fit time constraints, student abilities, and student interests.

Mr. Mattr chose to design a unit on plants and plant growth to meet students' interests and based upon the state and national standards for science. The unit focused on encouraging students to generate testable questions and then to design experiments to answer their questions. Ms. Vee's thematic units on ocean habitats and forestry conservation were developed after her students participated in "Fun Friday" events. Students watched videos, participated in activities and engaged in large group discussions on Fridays early in the school year. From the information gained about student interests and abilities, and taking into account Native American cultural characteristics, Ms. Vee designed her science curriculum.

Appropriateness of Activities

Teachers using FOSS kits did not question the appropriateness of the activities. They appeared to trust the selection of the kits by district committees for the grade level in which they taught. The kits also have a designated grade level focus that teachers relied on for appropriateness for their students. Teachers did not describe about how the kits accommodated students' abilities beyond stating that they selected FOSS activities that could be completed and that were of interest to students. Several teachers described the lessons from the kits as being student-centered because the students were actively involved in the activities. Ms. Kelly stated that science learning, "is a process. It involves building on the knowledge that you have, using what you know, forming a hypothesis, making a prediction, what do you think will happen and not just stopping at that…If I know this, if I think this will happen, what can I do to find out? …How am I going to test what I think?" Classroom observations, however, suggested that the teachers implemented the lessons in a structured and teacher-centered manner. Students were able to complete activities and participate actively in the lessons, but the lessons were highly structured by the teacher.

Activities appeared to meet the teachers' goals related to social skill development, following directions and completing tasks. Teachers suggested that they selected student groups for science activities to enhance learning. Mr. Goodman stated,

> I'll put certain students together because I know they will function as a group because of how well they can get along with others, or work with others. I also group them so some lows are with some average learners so they can help each other. Maybe some highs are with some average learners so that their groups are made up of enough different types of ability levels and learning styles that they can kind of enhance each other's learning.

New teachers in this study spoke of keeping in mind diversity issues when selecting student groups and activities.

Mr. Mattr and Ms. Vee conducted activities in which students engaged in discussion beyond "right answer" questioning. Observations showed student being encouraged to generate their own questions and to determine which observations they were to collect and record about their investigations. Ms. Vee explained, "it [activity] has to fit their [students'] ways of thinking".

Types of Student Thinking and Classroom Discourse

Teachers spoke of problem-solving, in-depth thinking, drawing conclusions and asking open-ended questions when discussing student thinking during science lessons. Teachers appeared to believe that the FOSS kits promoted scientific thinking processes such as making inferences, identifying patterns, manipulating data and drawing conclusions. Ms. Brandon used numerous questions throughout her science lessons, but most pertained to observations or were lower order questions (eg. What did you observe? What did you write in your logs?) rather than open-ended questions (eg. What if … happens? I wonder what would happen if…?). However, in her interview, she stated that she encouraged students to share their thoughts and ideas by offering feedback such as, "That's a great idea. Let's think about that for a minute… Let's see what we can find out outside of class." Few students generated their own questions, and those asked were not routinely answered or addressed during classroom observations. Researchers concluded that much of the whole group discussions were primarily teacher-directed and students predominantly answered questions that the teachers asked. In addition, there was no observational evidence indicating that teachers identified misconceptions or addressed them in class. Two teachers talked about misconceptions in their interviews, but did not elaborate how they challenged the misconceptions with their students.

There was some evidence to suggest that new science teachers provided an environment for emotional risk taking by students. Students were encouraged to think about their observations, talk to each other about what they observed, and use data to draw conclusions. This was particularly evident for students of Mr. Mattr's 5th grade science class. In a number of the profiles, classroom management issues created a barrier to classroom discourse and effective engagement in some of the activities observed. In two cases, teachers canceled the activities because students were not focused on the activities being conducted, and the classroom environment was one of chaos.

Teacher Role in Class and Discourse

Teachers describe themselves as "facilitators" or "guides" in the classroom, not dispensers of knowledge. They viewed their roles as selecting the activities for students, and orchestrating the activities for students so that they could learn science for themselves. Most teachers explained the need to provide students with basic science information before letting them participate in activities. Observations revealed a teacher-centered approach being used where decision-making power was held primarily by the teacher. A noted exception was Mr. Mattr's class in which he guided student discussions using probing questions so students could formulate their experimental designs of testable questions about plants and plant growth. Students generated questions and actively interacted in a discussion among themselves with little involvement from the teacher.

Assessment

Most assessments listed by teachers and observed by researchers were informal and formative. Among assessments used were observations, small and large group discussions, student log responses, pictorial responses, worksheets and project results. Only three teachers used formal tests and quizzes to assess student learning. Teachers explained that many of the assessments were found in the FOSS kits. Additionally, the assessments provided teachers with information about how well students worked in groups and followed directions. Teachers were observed walking around their classrooms and interacting with students throughout the inquiry lessons. Ms. Cam conducted morning meetings to review science concepts and to determine what modifications were to be made for the day's science lesson. There was little evidence to assert that assessment was used to tailor curriculum and instruction.

External Resources

Teachers listed numerous external resources that aided their teaching of science, most frequently noting mentor teachers and computer resources including the Internet. The mentor teachers were designated solely because they were more experienced and willing to assist the teachers. Mr. Beane talked of a middle school science teacher and school principal as key educators he relied upon for help in teaching science. Mr. Beane also mentioned the Science

Museum and the state science teacher organization (MnSTA). In addition, Mr. Beane's students recycled aluminum cans to augment the school's science materials fund. This fund permitted the purchase of additional materials to enhance his own science instruction as well as that of the middle school science teacher who served as one of his mentors.

Findings from the Secondary Group

Context

Ten participants who taught in secondary grades participated in this year's study. Two (Ms. Kay and Ms. Tee) were student teachers; five (Mr. Ehm, Mr. Beady, Mr. Double, Ms. Erikson, and Ms. Beach) were first-year teachers; three (Mr. Olafson, Mr. Larson, and Mr. Mizz) were second-year teachers. Four were female (Ms. Kay, Ms. Tee, Ms. Erikson, Ms. Beach) and six were male (Mr. Beady, Mr. Double, Mr. Ehm, Mr. Mizz, Mr. Olafson, Mr. Larson).

All were teaching within their licensure areas and all were certified (or certifying) to teach grades 5-12 except one; Ms. Beach held a degree in social science and had a K-8 license that included a 5-8 general science, and a social studies endorsement. She was observed teaching seventh/eighth grade general science and was responsible for teaching all subject areas to seventh and eighth grade at a charter school with an open/thematic concept. Seven of the teachers had completed (Mr. Beady, Mr. Double, Ms. Beach, Mr. Ehm, Mr. Mizz) or were completing (Ms. Kay, Ms. Tee) a fifth year certification program.

Teachers were asked to select one class to serve as a lens for the purposes of this study. For each teacher, this class took the survey, was observed twice, and was the focus of the interview. Four teachers selected a tenth grade biology class (Mr. Beady, Ms. Erikson, Mr. Double, Mr. Ehm), one selected a seventh grade life science class (Mr. Larson), and five selected general science classes ranging from seventh ninth grade (Ms. Kay, Ms. Tee, Ms. Beach, Mr. Mizz, Mr. Olafson).

Participants taught in areas representing a range of population densities from rural to urban. Six taught at public schools (Mr. Beady, Ms. Erikson, Mr. Ehm, Mr. Mizz, Mr. Olafson, Mr. Larson), while three taught at college-prep private schools (Ms. Kay, Ms. Tee, Mr. Double) and one taught at a charter school that used an open/thematic concept (Ms. Beach). None of the profiles indicated significant diversity was present in any of the classes observed. Almost all participants were in their mid-to-late twenties, and one was in her mid-thirties (Ms. Tee). Key information about the contexts of this year's secondary teachers appears in Table 2.

Table 2

Summary of Contexts of Secondary Science Teachers

Pseudonym	Year of Experience	Subject Taught	Grade Taught	School Type	Gender
Ms. Kay	student teacher	general science	9th	private	female
Ms. Tee	student teacher	general science	7th	private	female
Mr. Beady	1st	biology	10th	public	male
Ms. Erickson	1st	biology	10th	public	female
Mr. Double	1st	biology	10th	private	male
Mr. Ehm	1st	biology	10th	public	male
Ms. Beach	1st	general science	7th-8th	charter	female
Mr. Mizz	2nd	general science	9th	public	male
Mr. Olafson	2nd	general science	9th	public	male
Mr. Larson	2nd	life science	7th	public	male

Kinds of Activities

The secondary science teachers in this year's study used a variety of learning activities. Seven teachers indicated in their interviews that they used cooperative-learning or group work (Mr. Beady, Mr. Larson, Ms. Kay, Mr. Double, Ms. Tee, Mr. Ehm, Mr. Mizz). While many (Ms. Kay, Mr. Double, Ms. Tee, Mr. Ehm, Mr. Mizz, Mr. Larson) were effective in their usage of cooperative-learning (MnSTOI), two (Mr. Beady, and to a lesser extent Ms. Kay) appeared to have some difficulty arising from classroom-management problems (MnSTOI). Mr. Beady experienced discipline problems during cooperative learning that hampered student learning (MnSTOI), while Ms. Kay expressed concern about classroom-management during cooperative-learning activities (MnSTII) and was becoming more effective at classroom-management (MnSTOI). In their interviews, Mr. Double and Mr. Ehm expressed some concern about using cooperative-learning activities and group work because of perceived parental and administrative expectations about exam results. In contrast, Mr. Mizz experienced significant positive feedback from students and parents after using cooperative learning and other creative ways to engage students in lessons (MnSTII).

Other learning activities that were identified during observations or described in interviews included field trips (Ms. Beach), stations (Mr. Beady, Mr. Larson), independent student projects (Mr. Double, Mr. Ehm, Mr. Mizz), Y-charts (Mr. Beady), and labs (Ms. Erikson). Two profiles indicated that students spent a significant amount of time in passive roles. Mr. Olafson stated that the ratio of seatwork/lecture to lab activities is "unfortunately about 100 to 1 easy. 1000 to 1" (MnSTII) and Ms. Erikson indicated she lectures about 60% of the time (MnSTII).

Two of the profiles provided definitions of what constituted an activity for the teachers. Ms. Beach indicated that an activity "is anything that students do that gets them actively involved with science" (MnSTII). Ms. Tee appeared to hold a highly inclusive definition, indicating that textbook reading was an activity if done at appropriate times in small bits to help develop a concept (MnSTII).

Appropriateness of Activities

The profiles examined for this year's secondary science analysis did not yield sufficient evidence to discern any trends or to draw any significant assertions relating to appropriateness of activities selected by the teachers.

Types of Student Thinking and Classroom Discourse

In several of the classrooms observed, discourse was observed that explicitly empowered students to express their ideas, understandings, and opinions (Mr. Double, Ms. Kay, Ms. Beach, Mr. Larson, Mr. Mizz). When asked in his interview about the role of discussion in class, Mr. Double answered, "I want them to have an opportunity to share what they know. I know from personal experience that I learn best when I have the chance to share my thoughts. I want kids to feel comfortable doing so in my classes." Mr. Double did this in both lessons observed (MnSTOI). Ms. Kay attempted to engage her students in class discussion and brainstorming. After clarifying her expectations about student involvement and prompting the class three times to participant using leading questions, the students began to open up (MnSTOI). Ms. Tee engaged students in several large- and small-group discussions in both lessons observed (MnSTOI). Ms. Beach and Mr. Larson invited students to think critically and express their personal opinions about ethical issues such as using pigs as organ donors for humans. (MnSTOI, MnSTII). These beginning teachers (Mr. Double, Ms. Kay, Ms. Beach, Mr. Larson, Mr. Mizz) were successful with the techniques they employed to engage students.

At least two of the profiles provided evidence that teachers were actively fostering an environment conducive to the kind of emotional risk-taking involved in meaningful learning. Twice during one of his observations, Mr. Mizz asked open-ended questions related to propulsion and why things "go", then had each student write down their thoughts on the question before sharing with their neighbor or eventually with the large group (MnSTOI). When asked why during his interview, he said some students would not even try to explain in a large group unless they had an opportunity to respond to themselves first. Mr. Larson, too, showed sensitivity to such needs through expectations he establishes early in the semester, "You don't have to like the person sitting next to you, but you do have to respect them" (MnSTII), and by defending students should they be criticized for asking questions (MnSTII).

Two teachers expressed a desire to strike a balance between student-centered and teacher-centered approaches. In these classrooms, students did have a voice, but the teacher provided clear parameters and structure within which students operated. Mr. Larson aimed to establish such a balance in his teaching. The inquiry that unfolded in his classroom was quite structured and guided carefully by the teacher (MnSTII, MnSTOI). He implemented numerous hands-on activities for his students, but still lectured regularly. Likewise, Mr. Ehm valued a balanced approach. In his interview, Mr. Ehm recalled a video he saw in graduate school that described research comparing traditionally taught biology courses and constructivist-based biology courses at the college level. He indicated that a combination of the two approaches worked best, especially for a college-prep school.

A number of the secondary teachers in this year's study indicated a desire to challenge students to think critically and to engage in meaningful discussion, as opposed to focusing primarily on memorization. These intentions, however, met with mixed levels of success. For example, in Mr. Beady's classroom, higher-order thinking was observed in small groups during discussions on ethical issues related to cloning (MnSTOI). His interview confirmed that one of his goals was to promote this kind of thinking. Classroom-management issues, however, lessened his effectiveness (MnSTOI). Mr. Larson, too, indicated that he aimed to train his students to be thinkers, and not just to memorize (MnSTII). Mr. Olafson also recognized the value of critical thinking; in his interview he stated, "They [students] always say, 'What are we supposed to memorize? What are we supposed to memorize?' And it doesn't work that way...I try to install [sic] that sort of critical reasoning, scientific method of looking at things." (MnSTII) However, it was clear that Mr. Olafson's efforts met with limited success in this regard. In particular, Mr. Olafson shared his frustration about designing inquiry activities. "I don't know how to produce...something that would help them with science inquiry. That's really hard. I mean I've tried it and it's just failed really bad." (MnSTII) He also indicated that elements that result in an engaging class discussion elude him and while compelling class discussions spontaneously arise on occasion, "Other days it's plug and chug". (MnSTII)

Teacher's Role in Class and Discourse

Five of the secondary teachers in this year's study indicated that their role in the classroom was to facilitate learning in a supportive role, as opposed to dispensing knowledge for students to collect (Mr. Mizz, Mr. Double, Mr. Ehm, Mr. Larson, Ms. Beach). For example, in their interviews both Mr. Double and Mr. Ehm indicated they felt students learned best from each other, and that their role was to help students get to the point where they could effectively interact with each other on topics (MnSTII). Mr. Mizz and Mr. Larson also described their role as facilitators of learning (MnSTII). Ms. Beach devoted a significant amount of time and energy towards coordination of outside resources and contact people, as well as to planning for field trips (MnSTII, MnSTOI). She was committed to initiating learning in authentic contexts as much as possible and even commented, "It would be a heck of a lot easier just doing a chapter in a text." (MnSTII)

The two teachers brought different perspectives on their role in the classroom. Ms. Erikson saw her role as teacher to be more controlling than collaborative with students. In addition, Mr. Olafson, a second year teacher, was still struggling to clarify his own understanding of his role as teacher. As he wrestled with tension between various roles, he was focused on level of engagement and motivation of students; concern about guiding student towards deep understanding of key science concepts was conspicuously absent from his perspective. In his interview, he stated,

> "Lately I've been getting a little down on the profession so I feel a little bit more like a babysitter than anything. But I don't know. Defining that [his role] is really tough. Sometimes I think of myself as just the person who exposes them to certain knowledge and that's one way. Other times I feel like I am a babysitter. Other times I feel like the teacher is meant to be there as a counselor. So it really depends on the day. Ideal days it would be someone that leads a discussion in science. That would be ideal. Those are the days that are the most fun for me...I think they have learned even more but again it's that energy level is really high, they're all on topic, it's really interesting and they want to know something about it. It's just one of those serendipitous, magical moments." (MnSTII)

Three teachers (Ms. Kay, Ms. Tee, Mr. Beady) appeared to take on a role congruent with facilitator of learning, but specific evidence is less than clear in their profiles. All three of these tachers took on an active role in classroom discourse and valued student interaction during lessons (MnSTOI).

Assessment

Most of the teachers used informal and student-based/self assessment in class (Mr. Ehm, Ms. Beach, Mr. Double, Ms. Kay, Ms. Tee, Mr. Beady, Mr. Mizz). Ms. Tee had students journal on their learning; for example, she had students journal for three minutes on how the systems of the body function together. Mr. Mizz also used journals as an assessment tool. Of note is that while Mr. Beady did use informal assessment, his effectiveness was limited in this regard due to classroom-management issues (MnSTOI, MnSTII). If and how these teachers used the results of informal assessment to tailor instruction and curriculum to specific student needs was, unfortunately, unclear based on this year's profiles.

In terms of grade-related assessment, all of the teachers used formal tests as one of the measures of student learning. Ms. Erikson used traditional summative assessment instruments such as chapter tests made up of multiple choice and essay questions, as well as some quizzes. Mr. Olafson also used end-of-chapter tests and quizzes, indicating his reasons for these methods were that they were "easy and fast" (MnSTOI post-interview). Four teachers used alternative assessments, but still relied on formal tests because of expectations stemming from teaching at a college prep school (Mr. Ehm, Mr. Double, Ms. Kay, Ms. Tee). Mr. Larson based student grades on assessment tools such as Minnesota Graduation Standards Performance Packages[4] multiple-choice tests, worksheets, and practical lab tests. Mr. Mizz and Ms. Beach also gave occasional tests, but their weight towards final grades was limited, for example, not more than 30% of a student's final grade in Mr. Mizz' classroom.

Only one teacher reported the regular use of the Minnesota Graduation Standards and accompanying performance packages (Mr. Larson, MnSTII). This is a conspicuous and noteworthy absence.

Two teachers indicated a very limited use of findings from student assessment to alter upcoming curriculum and instruction. Mr. Larson and Mr. Olafson both referred to minor adjustments to planned curriculum, although it was clear that the primary purpose of student assessment was to assign grades (MnSTII). Whether the other teachers in this year's secondary science study used grade-related assessments to tailor curriculum and instruction was unclear from the profiles.

External Resources

The teachers used a variety of external resources in their classrooms. Ms. Kay, Mr. Mizz, and Ms. Tee used the Internet regularly as a source of ideas or to find teaching materials. Seven teachers (Mr. Mizz, Mr. Double, Ms. Kay, Mr. Ehm, Ms. Tee, Ms. Beach, Mr. Larson) had access to computer labs, many of which could be used for virtual dissections or computer simulations. Mr. Mizz, Mr. Ehm, and Ms. Erikson had easy access to a television and VCR unit, while Mr. Double had access to exceptional audiovisual technology, including a built-in LCD to show videos and make PowerPoint presentations. Mr. Olafson brought in current news items and articles for students to consider (MnSTOI, MnSTII). Others relied on people such as master teachers, other teachers, peers in the masters program (Ms. Kay, Ms. Tee), and local community experts (Ms. Beach).

Findings about the Researchers and Process

Beyond the findings generated about individual teachers and their practice, this research project also produced findings related to both the researchers and the development and functioning of a statewide research network. The findings reported here come from a variety of data sources including: director observations; minutes from network meetings; revision of documents and research procedures over the course of the project; and questionnaires completed by the researchers.

The Process

The membership of the research network is composed of researchers from public and private institutions and two project co-directors. The co-directors are responsible for financial planning, professional development, and management of the research and data analysis processes. The entire group worked to select and modify the instruments used and to develop common research protocols. More detail about the network's organization and functioning can be found in the proceedings from the 2001 AETS annual meeting.

Over the course of the project we have learned that it is unrealistic to adopt existing research instruments without expecting to modify them to address your own research questions. Instruments were modified to collect information that aligned with our state teaching goals. In addition, we found that once instruments had been initially modified, continual revision of the instruments and research questions was necessary to ensure that we were collecting the necessary information. This meant that as the network evolved, an emphasis was placed on one instrument at a time. Data collected with that instrument was examined by the group, which allowed us to focus on alignment between research questions, the instrument and the data collected to answer the questions. Further modifications were also necessary as each new level of data analysis was achieved.

For example, we initially used the TPPI for our teacher interviews but after our first year, we found that questions could be deleted which did not directly relate to our research questions. Further, many questions were modified to related more explicitly to our research questions. After the first year of profile writing, it appeared that the background of the research participant might make a difference in the type of data that was included in the profile. In response, the TRN decided to collect researcher demographics so this variable could be examined. In essence, the researchers contributed to the study as participants. Finally, now in our third year of data collection, we are having trouble determining whether a profile should include teacher data from multiple years of observation or whether each year's data should exist as a separate profile.

Findings about the process also relate to how we work as a network with individual researchers. All members of the network arrived with different background knowledge and experiences. Some were science content experts while others worked in mathematics. Some came from education departments with extensive field observation experiences and others, professors in mathematics or science, had never been in a K-12 classroom. Specialties included elementary, middle and secondary education specialists and scientists with backgrounds in chemistry, biology, physics and the earth sciences. Some believed quantitative data was the only way to answer any research question while others had extensive experience in qualitative methodology.

This diversity required that the group spend time developing common understandings of terminology used both in the discipline and in the research instruments. New members enter the network feeling lost and needed to be inducted into the process to learn the language of the network and its culture. Professional development for the network included standards work, research methodology and utilization of the instruments. The process of professional development continues at each meeting with the introduction of some topic or activity from which all can learn. For example, we regularly agree to read one or two books that are discussed at an evening session at our network meetings.

A final lesson learned about operating as a research network relates to the problems that arise due to technical details. With different computer platforms, operating systems, and software, electronic files do not consistently transfer with ease. Voice activated tape recorders, used during the teacher interviews, lose details in noisy environments. Incorrectly completed bubble sheets from surveys slow down the analysis process when data must be recoded. Teachers may lose interest in participating when universities do not produce promised stipends in a timely manner. These points may seem trivial but establishing and maintaining a network over a period of years requires attention to details of these sorts.

The Researchers

Most of what we have learned about researchers can probably be summarized with the observation that we are all human. We have had problems with miscommunication, time management, determining rewards, and attrition, but the result is still an active group that does its best to produce quality data that will allow us to better understand Minnesota's beginning teachers.

Initially we believed that financial rewards would provide strong incentives for researchers, but we were wrong. Although small grants are provided to each institution ($5,000 - $10,000) for support of the research process, no researcher receives enough money to reasonably compensate for the time involved. Nonetheless, researchers continue to contribute to the TRN. The insignificance of financial rewards as a motivator was reinforced this year when even the small stipends for researchers disappeared and people continued to participate. Although researchers participate for various reasons, many state that they remain because of the purpose of the network, a sense of accomplishment and the opportunities it presents for their own professional development.

The most nefarious problem for all of the research participants has been the amount of time the project requires. Each researcher who participates has a fulltime teaching load of about 12 credits. Besides this teaching load, most are also involved in other service projects or research. When we started the project, we all assumed that we could investigate many more teachers than proved to be reasonable. Each researcher now investigates two teachers and even with this load, the duties of an academic career make it difficult to maintain the group's agreed upon timeline. It is a major role of the co-directors to encourage people to adhere to the network timeline without creating feelings of inadequacy.

Problems continue with miscommunication about procedures and terminology. Like students entering a K-12 classroom or university setting, each researcher brought his or her own beliefs about research, learning, teacher preparation and teacher observation skills to the research process. Trying to keep a common perspective for all those involved requires constant monitoring of the usage of language. Even after three years of work, a recent meeting of the group demonstrated that words such as "discourse", "activity", and "inquiry" suffer from multiple interpretations. This round of profile analyses also brought to light a difference in interpretation of one of the MNSTOI prompts regarding whether or not students learning had been achieved. Some people responded to the question from the perspective of whether they as researchers thought the students had learned while others stated the teacher's opinion about the extent of their students' learning.

We have lost some members of the network. Individuals have taken on new responsibilities at their institution, moved away, or retired. Even then, we do have one retired member still observing teachers and another who has moved to another state yet continues to analyze data for TRN. This is an example of how network members continue to participate despite changes to their individual contexts.

Conclusions

In conclusion, we are excited about the Teacher Research Network for a variety of reasons. We believe that the network provides an opportunity to learn more about beginning teachers and their lives in the classroom. We feel the project provides an important opportunity for longitudinal study of both individual teachers and groups of teachers. After the implementation of new teacher licensure standards in Minnesota, we feel the study can provide an opportunity to compare the reality of beginning teacher knowledge and skills to the state's new vision. We hope that our findings will have an impact on the future preparation of Minnesota's teacher of mathematics and science.

We also believe that a research network like ours serves as an important model for others involved in the preparation of teachers. If teacher educators are interested in learning about the impact of their program on students, the formation of a network may be one of the most powerful yet pragmatic approaches for fulltime educators to do this sort of work. We hope that our project and the lessons we have learned can serve as a model for others who are interested in the development of their own multi-institutional, longitudinal research collaborative.

Funding for this research was provided for by SciMath^{mn}(a publicly-funded statewide coalition for mathematics and science education)

Author's Notes

1. Teacher Research Network

These are the researchers who have contributed to the development of the instruments and/or participated in the collection of the data through the 2000-2001-research year.

Some researchers have moved to other institutions since their participation in TRN. Cyndy Crist, SciMath^{MN} higher education project director; George Davis, Minnesota State University Moorhead and Patricia R. Simpson, St. Cloud State University; TRN co-directors. Researchers: John Bauman, College of St.Scholastica; David Cline, Saginaw Valley State University; Alice Mae Guckin, College of St. Scholastica; Lynn Hartshorn, University of St. Thomas; Jean Hoff, St. Cloud State University; Bruce Johnson, University of Arizona; Michele Koomen, Gustavus Adolphus College; Carmen Latterell, University of Minnesota Duluth; Robert McClure, St. Mary's University; Jeff Pribyl, Minnesota State University-Mankato; Lon Richardson, Southwest State University; Teresa Shume, Minnesota State University Moorhead; Chery Takkunen, College of St. Scholastica; Tom Tommet, University of St. Thomas; Dori Tonnis, West Bend, WI; Alison Wallace, Minnesota State University Moorhead; Kay Wohlhuter, University of Minnesota Duluth.

2. The Salish Project was a multi-state effort to understand the practice of mathematics and science teachers who were graduates of the participating institutions.

3. Teachers in grades K-2 were not included in this study because their students could not complete the CLES2(20).

4. The Minnesota Graduation Standards are the state goals for student learning. Performance packages allow students to demonstrate their achievement of state standards and are required for high school graduation.

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AKA SCIENCE" AFTER-SCHOOL SCIENCE PROGRAM

Glenda Love Bell, Texas A&M University-Commerce

"aka Science" has been implemented in five elementary schools of varying arrangements: P-4, 3-4, P-2, and 5-6. Each school had two to four groups of 12 students each taught by a dyad of one in-service teacher and one pre-service teacher. Each school chose to have open recruitment. The proviso required by NETSMET was that the elementary "aka" participants reasonably reflect each school's demographics with regard to ethnicity, gender, socioeconomic status, special program support: ESL, Special Education, Gifted and Talented, and the regular education program.

Description of Program

The general framework for the "aka Science" after-school program was modeled after our Centers for Professional Development and Technology (CPDT) field-based program that functions within established partnerships with nearby school districts. Pre-service teachers were placed in teaching assignments with mentor teachers in elementary schools. The idea of the professional development schools is not only to promote rigorous professional development for teachers, but to engender high quality instruction and learning for all children.

In the "aka" program the pre-service teachers were paired with in-service teachers in the preparation and implementation of the program. Each dyad taught a group of 12 children hands-on, inquiry-based science lessons in eight-week rotations of one hour per week. The children in each school program were representative of the demographics of the school in which the program was implemented. The lessons for each eight-week rotation were focused on one general science topic such as chemistry, anatomy, etc. Last spring, a Family Science Fun Night culminated the after-school science program. The children and their parents actively engaged in science activities monitored by in-service and pre-service teachers and by NETSMET volunteers.

An important aspect of the program that contributed toward introspection into the teachers' beliefs was journal writing and evaluation of the program. The benefits to the school community were that the children had a productive activity in which to engage after school that also supported their academic work. An added benefit was the opportunity for children of diverse cultural commitments and with diverse learning needs had the opportunity to work together in a respectful way.

Professional development education in inquiry-based science was provided for all the teachers. In addition, the teachers received a small stipend. The in-service teachers were paid at the same school district rate as teachers who taught in after-school tutorial programs. The pre-service teachers received half the rate.

The framework upon which the "aka" program was designed is shown in Table 1. There are many similarities among the standards set forth in standards for professional development schools by the National Council for Accreditation for Teacher Education (NCATE, 2001), the National Science Education Standards (NSES, 1996), the framework for the Northeast Texas Science, Mathematics, Engineering, and Technology (NETSMET) framework, (2000) and the characteristics of Service Learning outlined by Mark Cooper in "The Big Dummy's Guide to Service-Learning".

Table 1.

Framework for NETSMET Model of Elementary Science Education Enhancement

Professional Development Schools Model	NETSMET Framework	National Science Education Standards
Maximize student achievement	Enhance scientific literacy and student achievement in science through inquiry learning	Scientific literacy for all students through inquiry learning
Rigorous professional development for pre-service and in-service teachers	On-going, rigorous professional development for primary through graduate school faculty and for participating pre-service teachers; an emphasis on inquiry learning, and integration with other content areas, especially with mathematics and technology.	On-going professional development for pre-service and in-service teachers: This includes science content, process skills, and pedagogy; and integration with other content areas, especially mathematics
University faculty is actively involved in a collaborative relationship of responsibility	Cultivate communication, networks, and active interrelationships among and between all collaborative members: P-12 schools, university, community, parents, and agencies.	Continuous dialogue and effort among all stakeholders to improve science literacy, including colleges and universities, nature centers, parks and museums, businesses, laboratories, community organizations and various media.
Provide opportunities for research	Provide opportunities for research	Provide opportunities for research
Provide challenging, equitable learning opportunities for a diversity of learners	Foster an appreciation of and active participation in mathematics, science, and technology by all participants: K-12 schools, university, community, parents, and agencies	Science learning excellence and equity for all students
Reflective learning regarding personal teaching practices	Focused reflection regarding, science, personal science learning experiences, and teaching practices	Structured reflection on science teaching practices
(NCATE, 2001)	(NETSMET, 2000)	(NSES, 1996)

Service- Learning:

Provides an avenue that targets specific academic goals and objectives.
Raises awareness of and enhances development of personal belief system that fosters caring for others.
Based on reciprocal relationship between service and learning.
Provides for focused reflection on their service and their experiences.

(Mark Cooper, 2001)

The Northeast Texas Science, Mathematics, Engineering, and Technology Collaborative (NETSMET), a schools/university/agency partnership, was formed to explore ways to improve science, mathematics, engineering, and technology education in our region. Members of the partnership include the university, two school districts, and an Area Health Education Center.

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The partnership chose to invest effort at the elementary level for several reasons: 1) Lack of attention to science at the elementary level; 2) Limited preparation of elementary teachers in science and inquiry-based pedagogy; 3) Current emphasis on problem-solving and critical thinking in all areas of education for all children; 4) Planting a vision of science as a route of choice and achievement for all children; 5) Scientific literacy that enhances daily living and eventual career choices; and, 6) Resultant longitudinal effects. It also gave the pre-service teachers an opportunity to work with the children and their families in a way not afforded in their internship/residency experiences. Participation in the "aka" program provided an opportunity for the pre-service teachers to experience the more community related realm of the real world of teaching.

The "aka Science" after-school program has benefited from an environment of moral and grant support through a University System initiative to enhance and improve the quality and productivity of educator preparation programs and to address the shortage of science, mathematics, and technology teachers in particular. The initiative promotes university-wide responsibility for teacher preparation and promotes school-university partnerships. These initiatives require change throughout the P-16 system. Education is still in the process of reform as we have stepped over the threshold from the industrial age into the information age and the 21st Century. The education system has the task of improving all students' performance as learners, critical thinkers, and problem-solvers so that all have an equitable opportunity to participate as active, contributing citizens (AECT, 2000).

Some of the most salient issues we have had to reconcile or deal with include people, programs, and policies such as state high-stakes accountability testing, current state-adopted science curriculum, recruitment of all participants, development of the NETSMET partnership, funding, the Regents' Initiative, and regular duties of university faculty.

This experience provides a lens that helps us all see how closely connected unseeming elements are to teacher preparation and to P-12 student achievement in science. The varied perspectives on science education and teacher preparation, brought into the process by members of the partnership, form the basis for on-going problem analysis and change. Sometimes, change is met with resistance. One of our major goals in our teacher preparation program is the development of teaching confidence and a life-long professional, caring attitude toward the teaching profession, toward peers, and most of all toward the children our interns/residents teach in our field-based program and those they will teach when they are certified and have classrooms of their own.

Further examination of this program and other similar programs will provide insight into their effectiveness to positively influence elementary student learning in science, into the sustainability of apparent changes in teacher beliefs, attitudes, and practices regarding science and science teaching, sustainability of institutional and public commitment to such programs, and into the long range effects of these programs on students' eventual choices and participation in challenging science courses in secondary and higher education.

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ELEMENTARY SCIENCE TEACHING ENHANCEMENT THROUGH A PROFESSIONAL DEVELOPMENT SCHOOLS MODEL

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A Program of Elementary Science Teaching Enhancement

This study on elementary science teaching enhancement was conducted in a program based on the professional development schools (PDS) model of teacher education and the National Science Education Standards (NSES, 1996). The premise being that if the PDS model can generally improve teacher preparation and P-12 education, perhaps, an integration of the PDS model with the National Science Education Standards can specifically guide improvement in elementary science teaching and science education. Through the Regents' Initiative, which will be described more fully later, the Northeast Texas Science, Mathematics, Engineering, and Technology Collaborative (NETSMET), a schools/university/agency partnership, was formed to explore ways to improve science, mathematics, engineering, and technology education in our region. Members of the partnership include the university, two school districts, and an Area Health Education Center.

Our state, like many others, faces a formidable challenge. That challenge is to provide a sufficient number of qualified classroom teachers for P-12 who must demonstrate an unprecedented level of content knowledge, instructional proficiency, and instructional effectiveness (Sid W. Richardson Forum, 2001). This shortage is acute in science, mathematics, and technology (Institute for School-University Partnerships, 2000).

The NETSMET partnership assembled a group of targets to enhance science education. The partnership chose an inquiry-based approach to course design for an integrated science course, for a required science methods course, and for the curriculum and professional development education for an after-school program, and for a summer science institute with a science camp embedded in it. See Table 1 for the framework that directed development of the NETSMET model of science education enhancement.

Table 1.

Framework for NETSMET Model of Elementary Science Education Enhancement

Professional Development Schools Model	NETSMET Framework	National Science Education Standards
Maximize student achievement	Enhance scientific literacy and student achievement in science through inquiry learning	Scientific literacy for all students through inquiry learning
Rigorous professional development for pre-service and in-service teachers	On-going, rigorous professional development for primary through graduate school faculty and for participating pre-service teachers; an emphasis on inquiry learning, and integration with other content areas, especially with mathematics and technology.	On-going professional development for pre-service and in-service teachers. This includes science content, process skills, and pedagogy; and integration with other content areas, especially mathematics
University faculty is actively involved in a collaborative relationship of responsibility	Cultivate communication, networks, and active interrelationships among and between all collaborative members: P-12 schools, university, community, parents, and agencies.	Continuous dialogue and effort among all stakeholders to improve science literacy, including colleges and universities, nature centers, parks and museums, businesses, laboratories, community organizations and various media.
Provide opportunities for research	Provide opportunities for research	Provide opportunities for research
Provide challenging, equitable learning opportunities for a diversity of learners	Foster an appreciation of and active participation in mathematics, science, and technology by all participants: K-12 schools, university, community, parents, and agencies	Science learning excellence and equity for all students
Reflective learning regarding personal teaching practices	Focused reflection regarding, science, personal science learning experiences, and teaching practices	Structured reflection on science teaching practices
(NCATE, 2001)	(NETSMET, 2000)	(NSES, 1996)

All science learning experiences provided through this program for in-service, pre-service, and 2nd grade through 6th grade students were inquiry-based. Learning was couched in experiences based on constructivist tenets of active exploration with concrete objects, understanding through interaction with science concepts, and extension of cognitive constructs about science and science learning/teaching through mental manipulations. University faculty Provided additional science content through scaffolding. Scaffolding, or guided learning, was used to assist the participants in making connections among their prior understandings, their active learning experiences, and new understandings and articulation of science concepts congruent with the way the scientific community understands science. The purpose of this study was to determine if the extent to which pre-service and in-service teachers engaged in hands-on, inquiry-based science learning had significant influence on their teaching practices. The extent to which participants might have had the opportunity to learn science in an inquiry-based format provided in the framework of this study is shown in Table 2. Several factors affected the extent of involvement. Some pre-service teachers engaged in all aspects of the program. Some who taught in the "aka Science" program did not take IS351 because it was not required when they were at that sequence in their course work. Some in-service teachers taught in the "aka Science" program and participated in the summer Science Institute and Camp. Some only participated in one or the other of the two programs.

Professional Development Schools Model of School Improvement

In the 1980's, professional development schools emerged as a model with high potential for improving teacher education and pre-kindergarten – twelfth grade education. As the notion of professional development schools has grown, so have the names by which they are called such as

Table 2.

Possible Extent of Science Inquiry Learning Experiences

Types of Inquiry Learning Experiences	Pre-Service Teachers	In-Service Teachers
1. "aka Science" curriculum professional development	1 and 4	1 and 2
2. Teaching in the after-school program	1,4, and 5	3
3. Summer Science Institute and Camp	1,2,3, and 5	1,2, and 3
4. Completion of ElEd 437 Science Learning: Science Field-Based	3 and 4	
5. Completion of IS351 Integrated Science	3,4, and 5	

professional practice schools, clinical schools, and school-university partnerships. So, what are Professional Development Schools? They are partnerships dedicated to innovative, shared responsibilities among (P-12) schools, universities, and communities in teacher preparation and teaching enhancement for both pre-service and in-service teachers. They promote inquiry-based, student-centered teaching practices and improved student learning at all levels (NCATE, 2001).

The National Science Education Standards set forth by the National Research Council in 1996 and the National Standards for School Mathematics set forth by the National Council of Teachers of Mathematics in 1989, led the way for other academic groups to establish national standards as part of the national education reform effort. Education is still in the process of reform as we have stepped over the threshold from the industrial age into the information age and the 21st Century. In 2001, the National Council for Accreditation of Teacher Education (NCATE) set forth national Standards for Professional Development Schools (SPDS). Their purpose was to provide a framework of rigor in the development, progress, outcomes, and evaluation of these partnership professional development schools (NCATE, 2001). The education system has the task of improving all students' performance as learners, critical thinkers, and problem-solvers so that all have an equitable opportunity to participate as active, contributing citizens (AECT, 2000).

In response to this dilemma, in 1999 the Board of Regents of our university system approved The Regents' Initiative and garnered grant funding to support it. A concerted examination of the systemic structure of education, how all the parts are related and function together, revealed the need for innovative, non-traditional ways of addressing education and teacher preparation if the above-mentioned challenges are to be met. The requirements of productive change is outlined in change theory: It is multifaceted, will occur over time, involves change in attitude and practices, requires economic and emotional support, and requires collaboration among the different interested entities (Cuban, 1988, NSES, 1996, Stiegelbauer, 1994).

We are in the third year of the initial five-year plan to enhance and improve the quality and productivity of educator preparation programs and to address the shortage of science, mathematics, and technology teachers in particular. The Regents' Initiative promotes university-wide responsibility for teacher preparation and promotes school-university partnerships (Institute for School-University Partnerships, 2000). These efforts build upon the work of Centers for Professional Development and Technology (CPDT), field-based teacher preparation programs, established during the 1990's (Sid W. Richardson Forum, 2001).

In it's eighth year, the CPDT structure of elementary teacher preparation at our university is designed upon the professional development schools model. The CPDTs each represent a collaborative effort that places much of the decision making process within the Instructional Leadership Teams (the interns/residents, mentor teachers, campus contact persons, principals, and university liaisons, or faculty) and the school district Steering Committees (university faculty, school district faculty and administrators, community leaders, and university students). This year long, field-based teacher preparation program requires a 15-week internship semester and a 15-week resident semester during which the interns and residents teach with practicing mentor teachers. This environment of mutual cooperation and active participation of all partners in the teacher education process provides an environment in which practitioners and interns/residents can identify and refine their teaching knowledge and abilities. The interns/residents benefit from the seasoned experience and knowledge of the mentors and the mentors benefit from the academic experience of the interns/residents (Northeast Texas Center for Professional Development and Technology, 2000).

A Constructivist Approach to Teacher Preparation

The constructivist model of learning theory suggests that the learner develops a way of knowing or understanding new concepts based on prior knowledge. Knowledge is not simply transmitted from one knower to another. The learner must demonstrate a curiosity about and interact and grapple with the concept to be learned. The more experienced knower acts as a coach and guide in facilitating the conceptual understandings of the novice learner (Bell, 1999, Driver, Asoko, Leach, Mortimer, & Scott, 1994; Piaget, 1970; Vygotsky, 1962).

The professional development schools model embodies the constructivist approach in teacher preparation. The pre-service teachers learn in a real-work setting under the guidance of a team of mentor teachers, school administrators, and university faculty. They have the opportunity to connect theory and practice as they observe, practice, reflect, and are mentored

(Darling-Hammond, 1994, Loucks-Horsley, S., Hewson, P.W., Love, N., & Stiles, K.E., 1998). These experiences contribute to their professional growth as reflective, child-centered practitioners, collaborative team players, who are more confident in their knowledge and skills and of their ability to function in the culture of schools and teaching (Book, 1996; Darling-Hammond, 1994; Levine, 1997, Loucks-Horsley, S., Hewson, P.W., Love, N., & Stiles, K.E., 1998, Tell, 1998). Since these experiences influence what they believe about teaching and their ability to teach, their beliefs may be a major factor in science education reform (Beck, J., Czerniak, C.M., and Lumpe, A.T., 2000).

The Dynamic Nature of a Small World System

A systems approach to education change directed development of this program. Upon analysis and evaluation of how this program might function within the larger education system, it was determined that implementation could not be linear, neither a top-down approach, nor a bottom-up approach. The interrelationships of the various entities required a dynamic model so that the best perspectives of each entity could be brought to the table. The model that seemed to best represent the dynamic relationships was the Small World Effect, a mathematical model, developed by Steven Strogatz and Duncan Watts (1998). They used a ring graph to demonstrate how a network comprised of elements with no obvious direct connections are related by six or fewer degrees of separation. In their quest for networks allowing the shortest path between any two points, they found that on a ring graph, if 1% or less of the total number of elements have long distance connections, then the average degrees of separation are about four. This is similar to a random network, but with more clustering, or direct, near connections. Strogatz and Watts examined three networks of which all connections were known: the neural network of Caenorhabditis elegans, a nematode worm, the grid of power stations in the western United

States, and a database of everyone who has ever acted in a feature film. They suggest this idea may be used for analysis of other neural networks, tracking contagious diseases, marketing on the Internet, and many other such applications. It seems credible as a tool for examining systems in education.

Sixteen elements that included people, programs, and policy were included as the most salient factors in the network, or partnership, that provided the environment for this study. They are listed in Figure 1. Small World Effect of Program Constituents and Elements. According to the 1% factor, only two distance connections would be necessary in this network to achieve the average of about four degrees of separation. However, three were used to emphasize the importance of the Regents' Initiative, the CPDT relationships, and the after-school and summer programs. This model demonstrates how closely connected unseeming elements are to teacher preparation and to P-12 student achievement in science. The varied perspectives on science education and teacher preparation, brought into the process by members of the partnership, formed the basis for problem analysis, implementation, and evaluation.

Planting Seeds of Vision in an Elementary Program of Enhancement

Elementary science education was targeted for these reasons: (a) Lack of attention to science at the elementary level; (b) Limited preparation of elementary teachers in science and inquiry-based pedagogy; (c) Current emphasis on problem-solving and critical thinking in all areas of education for all children; (d) Planting a vision of science as a route of choice and achievement for all children; (e) Scientific literacy that enhances daily living and eventual career choices; and, (f) Resultant longitudinal effects.

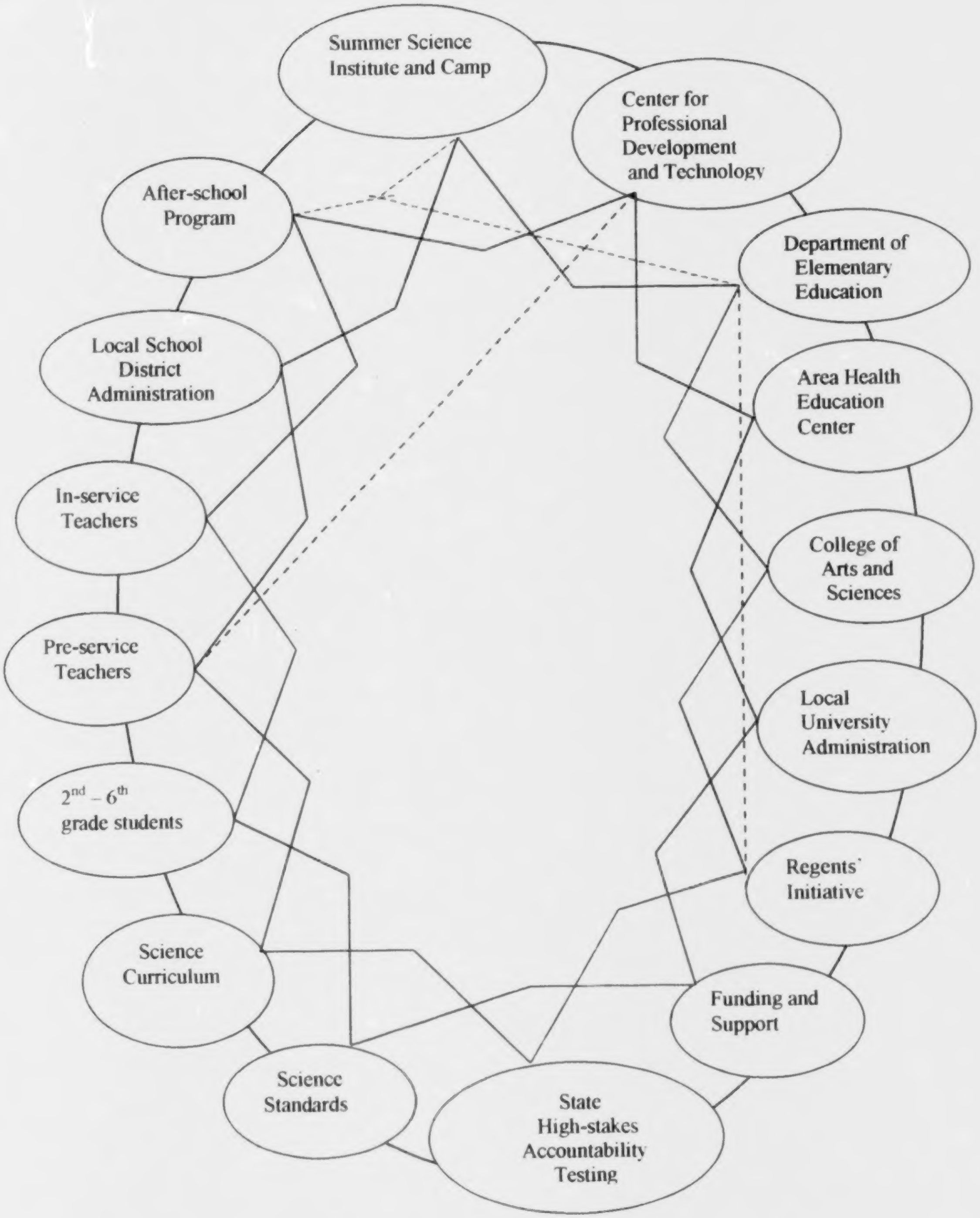
Summer Science Institute and Camp
Center for Professional Development and Technology
After-school Program
Department of Elementary Education
Local School District Administration
Area Health Education Center
In-service Teachers
College of Arts and Sciences
Pre-service Teachers
Local University Administration
2nd – 6th grade students
Regents' Initiative
Science Curriculum
Funding and Support
Science Standards
State High-stakes Accountability Testing

Figure 1. Small World Effect of Program Constituents and Elements

In response to and with support of the Regent's Initiative, a pilot program of science teaching enhancement was put into place in two elementary schools and one intermediate school located in two of the CPDTs. In addition, a summer science institute for college credit with a science camp for 2nd through 6th grade students embedded in the course was funded by an Eisenhower Professional Development grant and by a Regent's Initiative research grant. Interns and residents (students in the last two semesters of their professional development sequence), newly graduated students, and in-service teachers participated in both enhancement programs. University faculty provided instruction in the two programs. In addition, science methods instruction for interns was provided in a seminar/field-based setting. A small number of the interns completed a hands-on, inquiry-based integrated science course that relatively recently was added as a requirement of their individual degree plans. A Family Science Fun Night culminated the after-school science program.

The relationships already established through the field-based CPDT teacher preparation program facilitated the expediency with which the after-school programs were implemented and with recruitment for the summer science institute and the follow-through professional development education. The planning team for this cluster of enhancement programs consisted of university faculty and department chairs from the College of Education and the College of Arts and Sciences, an assistant dean, the campus director of the Regent's Initiative, local school district curriculum directors and principals, and the CEO and a program director from a health education agency.

Changing Professional Development to Change Teaching Practices

The purpose of this study was to determine if the extent to which pre-service and in-service teachers engaged in hands-on, inquiry-based science learning had significant influence on their teaching practices. Professional development with a cohesive group of participants, over time, has been found to engender the most effective results (Stiegelbauer, 1994). The context within which most learning took place was a model that closely resembled the professional development schools model. Pre-service teachers were paired with mentor teachers experienced in classroom practice. All kept reflection journals and received professional development education in science content and pedagogy. Their experiences in teaching children were considered a valuable part of their own learning experiences. University faculty acted as facilitators and consultants.

Participant Beliefs, Attitudes and Performance

Several measures were used to assess participant beliefs, attitudes, and performance. An adaptation of the Science Teaching Efficacy Belief Instrument (STEBI) (Riggs & Enoch, 1990) was used to measure general beliefs and attitudes about science and science teaching. Scores on the science domain of the test for state teacher certification and content pre and post tests were used. Journal responses, course evaluations, and survey data were used.

The "aka Science" After-School Program

The initial after-school program was an after-school inquiry-based, hands-on science program for nine groups of second grade through sixth grade students. A team comprised of a practicing teacher and an intern or resident taught each group of 12 students. Each segment, consisting of 8 one-hour sessions taught over an eight-week period, focused on one topic of science such as anatomy or chemistry. Prior to teaching in the after-school program, hands-on exploration of the science content, materials, activities, and teaching skills was provided for the instructional teams through professional development education taught by a university professor. "aka Science", a hands-on, inquiry-based curriculum developed by Hands On Science Outreach, Inc. was the curriculum chosen for the after-school program. This curriculum, with a strong emphasis on critical, probing questioning, manipulation of concrete objects and ideas, model building, and integration of mathematics, was comprised of kits that contain essentially all of the supplies and equipment needed by the children. A lesson plan booklet, provided for the teacher's use, guided the lessons and provided content background.

Decisions about participant recruitment and implementation of the after-school program were placed mainly with the cooperating schools. The only proviso, required by the planning team, was that the participants in the after-school program reflect the demographics of the school in which the program was implemented and that there be no participation fee. All schools met this proviso by including heterogeneous groups of students that highly correlated to each school's make-up by gender, ethnicity, socio-economic status, special education, English as a Second Language, and Gifted and Talented. No school charged a fee for participation.

At the beginning of the professional development education, prior to each 8-week student segment, a science content pre-test was administered to each teacher participant. After the participants had completed the professional development and had taught the 8 classes to the students a posttest was administered. In addition, a pre/post STEBI was administered to the participants. A pre/post content test was administered to the elementary students.

Elementary Education 437 Science Learning Field-Based

The nine pre-service teachers in this study completed the Elementary Education 437 Science Learning Field-Based course. This hand-on, inquiry-based course was designed to assist students in their understanding of how to teach science to elementary students using hands-on, inquiry based methods to inspire investigations, higher-order thinking, confidence, and an appreciation for science. Since most of these teachers were destined to teach in self-contained classrooms where they are responsible of all content matter, integration across content areas was an important component of this course. In addition to regular instruction by a university professor, the course included six and one hours of hands-on, inquiry-based instruction by a National Aeronautics and Space Administration (NASA) professional development specialist and six hours of hands-on, integrated, inquiry-based instruction by two Project Learning Tree (PLT) professional development specialists.

The pre-service teachers were administered a pre/post STEBI, generated weekly reflection journals, did a course evaluation, and completed a survey about inquiry-based teaching/learning. University faculty, whose regular assignments included acting as liaisons in the field-based teacher preparation program, mentored the pre-service teachers.

Integrated Science 351

In 1999 a required Integrated Science 351 course, taught in the College of Arts and Sciences, was implemented to enhance elementary education majors' science content knowledge and to help prepare them for the science domain of the state teaching certification test. A minimum of 85% of the course content was focused on science content. About 15% of the course content was based on professional development. Several studies suggest the most successful teacher education students are those who reflect upon their own current learning experiences, develop an image of themselves in their future roles as teachers, and make connections between present and future experiences (Centre for Academic Practice, 2000; Chambers & Stacey, 1999; Key, 1998; Swafford, Jones, Thornton, Stump, & Miller, 1999). A substantial effort was made through course assignments and class discussions to cause the students to reflect upon their personal image of their future roles as teachers. Seven of the pre-service teachers had taken this upper division course that is, generally, completed shortly before the internship (first) semester of field experience.

Summer Science Institute and Science Camp

In a three- week, Eisenhower and Regents' Initiative funded summer science institute, there were 17 in-service participants and 5 pre-service participants. The course was cross-listed so that those participants who had graduated could receive graduate credit for the course and those who had not graduated could receive undergraduate credit. Forty-three second grade through sixth grade students participated in a seven-day summer science camp that was embedded in the course. The 22 adult participants were divided into 10 teaching teams of two or three. Pre-service teachers were paired with in-service teachers. While five of the teaching teams were in class, the other five teams were teaching the elementary students who were divided into groups of eight or nine. The course design included content instruction, hands on learning of the activities that would later be taught to the students, a component on teaching children who represent diverse socioeconomic and cultural commitments, a component on teaching children with diverse learning abilities and needs, and a component on cross curricular integration with an emphasis on reading, writing, and mathematics. The camp activities for the students were completely hands-on, inquiry based.

The adult participants were administered pre/post content and content tests and pre/post STEBI assessments. Each individual generated a background survey, an end-of-course evaluation, and daily reflection journals. Four in-service teachers participated in the after-school program and in the summer science institute.

Classroom Observations

Classroom observations occurred in several different settings. The interns were observed in their intern program a minimum of six times per semester, at least once by their university liaison with the balance by their mentor teachers. The evaluator for the Eisenhower program observed the in-service teachers. During the after-school program visits were made to observe each team with their students and observations were made of the summer institute participants teaching their groups of elementary students.

Program Analysis and Findings

Pre-Service Teachers

In any one of the learning situations, isolated from the others, there was often no significant gain in confidence and attitude toward science and science teaching. However, pooled data using a modification of the STEBI, surveys, journals, and observations, with increased participation in these learning situations significant gains began to emerge. The more exposure and active involvement with inquiry-based learning the more significant gains were established. Pre-service teachers who taught in the after-school program and/or participated in the Summer Science Institute were more likely to choose to teach science lessons or integrate science in other content area lessons for formal observations by their liaisons or mentor teachers. On course evaluations students' comments that will follow indicated that they perceived inquiry learning was valuable to them.

I really learned a lot from the inquiry learning lessons.

I think it reflected on the ExCET.

I really enjoyed the science content. They were hands-on and very fun.

Journal reflections and interviews indicated that, as a result of increased confidence in science content and teaching skills, the students intend to incorporate more inquiry-based science teaching into their practices when they have their own classrooms.

My teacher doesn't teach science, but when I get my own classroom I'm going to teach hands-on science because it is fun.

My teacher doesn't teach much science, but she let me include science in my observation lesson.

"aka" helped me to see that science is not something to be scared of. It also gave me a few ideas as to how to bring science into my classroom.

I have learned many new lessons that I plan on using in my classes next year. (First contract teaching position.)

I can see how the students learn much more from this approach rather than a lecture approach.

As an eventual first semester teacher, one of the students had completed the IS351 course, the ElEd437 course, and had participated as a pre-service teacher in the after-school program. During her first semester as a certified teacher she received praise from both her school principal and her team members regarding her knowledge and willingness to suggest and bring ideas for integrating content across the curricula and for integrating science into regular teaching practices.

Thirty pre-service teachers' scores on the science domain of the state test for teaching certification were analyzed. Many had completed the IS351 course and all had been taught ELED437 by one or the other of the two elementary education faculty who also provided instruction in the professional development education for the after-school program and in the summer science institute. First a comparison was made between each individual's total score and the score made on the science domain. Then, the total score was subtracted from the science domain score. An average difference for the group was ascertained. Then the average difference scores of 10 pre-service teachers, who had participated on some level in the after-school program and/or the summer science institute, were compared against the average difference scores of the whole group. The average difference scores of a random sample of 10 pre-service students who were not taught by the two instructors were ascertained. A comparison was made across the three samples. For the group of thirty, it was found that on average their science domain scores were 2.56 points higher than their total score. For the group of program participants, on average their science domain scores were 3.44 points higher than their total score. For the random sample of 10, on average their science domain scores were about .5 points less than their total score. See Table 3 for a comparison of Average Difference Scores.

Table 3.

Average Difference Scores on Science Domain of the ExCET

Group of 30 mixed program participants and non-participants taught by two program administrators	Group of 9 program participants taught by two program administrators	Random Sample of 10 Others Non-program participants and none taught by either of the two program administrators

A point of interest is that students in the group of 30 who failed the state test for certification maintained a 2.5 average difference score in the science domain of the test. Their average difference score matched the average difference score of the whole group. Further research is needed to verify whether there is an authentic relationship between extensive inquiry-learning experiences and science scores on the state accountability test.

Six of the nine pre-service teachers had completed the IS 351 course. Of these, the final semester grade was a B for four of them and an A for two of them. The normal sequence of participation in inquiry learning provided in this study and completion of the state test for certification is as follows: IS 351 before internship/residency, ElEd 437 during internship, professional development education for the after-school program, completion of the state test for certification, and professional development education/course work in the summer science institute.

In-Service Teachers

Surveys, journal responses, evaluations of the summer science institute and of the professional development education for the after-school program, and observations indicated significant gains in improvement in beliefs and attitudes toward science and inquiry-based science teaching. Findings were similar to those of the pre-service teachers. The more exposure and active involvement with inquiry-based learning, the more significant gains were established. The in-service teachers were more likely to indicate intent to teach inquiry-based science and to actually implement inquiry-based science into their teaching practices.

Comments on evaluations of the professional development education and the teaching experiences in the after-school program indicated that some of the teachers concerns had been mitigated by their own learning experiences.

We had a minimum of student behavior problems. (Note that the demographics of the elementary student participants closely matched the demographics of the school.)

I was happy to see students love doing science.

The fast pace of the lessons and the amount of material to cover made me stay structured and focused on the objective.

It helped me to know that science can be fun and isn't too difficult.

It gave me ideas on how to bring experiments into the classroom.

At least half of the in-service respondents indicated that they incorporate more science in their regular classroom teaching practices. All respondents indicated that one of the most important benefits was an increase in science knowledge.

Journal responses from some of the in-service teachers indicated concerns about inquiry-based teaching, raised confidence, and increased knowledge.

This science camp has presented many challenges for me as a seasoned teacher.

I have begun to see new ways of motivating and teaching my students in the classroom that will correlate all subjects.

The inquiry method causes the students as well as the teachers to become higher order thinkers.

(Pre summer institute journal.) *I was a little nervous about this class. When I was in school, science wasn't "fun". It was a lot of bookwork without much hands-on. I grew up believing that science and experimenting were dangerous.* (Post summer institute journal.) *I do not feel the (content) test showed how much I learned. It didn't have a place to put what I now know about cabbage juice indicators, pH, bubbles, roller coasters, and bouncing balls. I never would have believed all the things I would get (ideas) from these 2 weeks. I am much more comfortable with science.*

Combined Pre-Service and In-Service Data

A modification of the STEBI was administered to both pre-service teachers and in-service teachers. All original questions of the STEBI-B were included. Four additional questions on comfort with open-ended questioning, open-ended student assignments, and assessment of open-ended assignments were added. A comparison of total pre and post assessment scores on the modified STEBI indicated an important improvement in beliefs and attitudes toward science and science teaching. See Figure 2 for Modified STEBI Results.

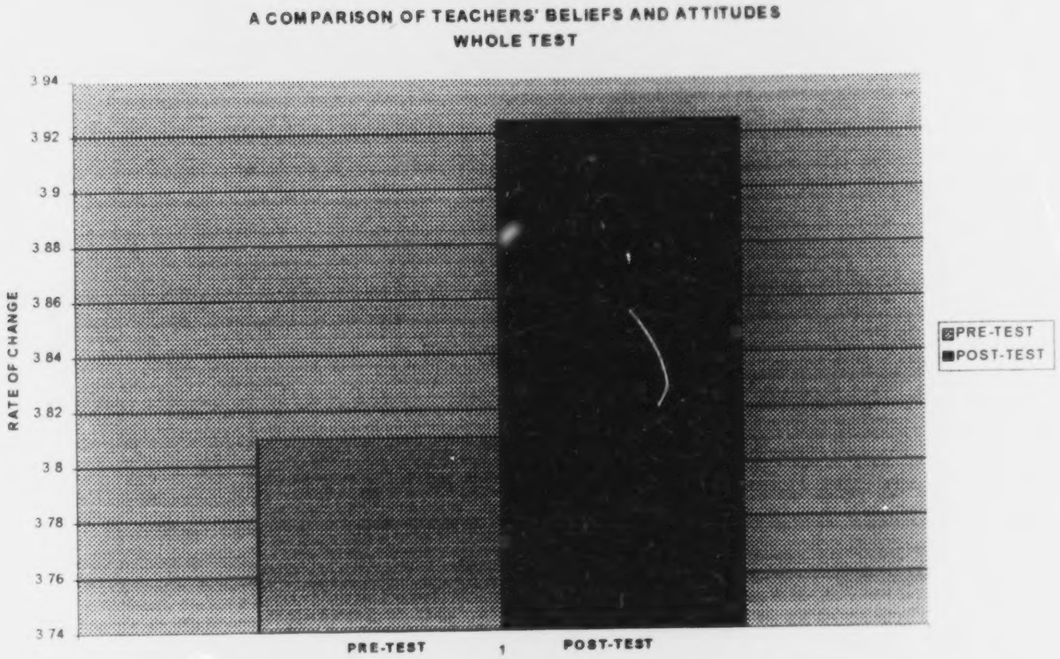

Figure 2. Modified STEBI Results

Results on the pre/post content tests administered to the after-school teachers and the pre/post content tests administered to the summer science institute teachers indicated a significant increase in science content knowledge See Figure 3 and Figure 4).

All of the teachers in this study, both pre-service and in-service, were representative of most elementary teachers in that most had taken only three or fewer laboratory courses in their undergraduate work. Only a few had taken more. Five of the in-service teachers taught science in a departmentalized setting, meaning they taught only science or taught all science with one class of social studies. Most of the teachers taught in self-contained settings where they taught all content subjects. Two were reading specialists. There was no significant difference between the ways the pre-service teachers scored on the content tests compared to the in-service teachers.

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However, as noted earlier, there was a considerable difference between the scores of the pre-service teachers in this study ad those not in this study on the science domain of the state accountability test.

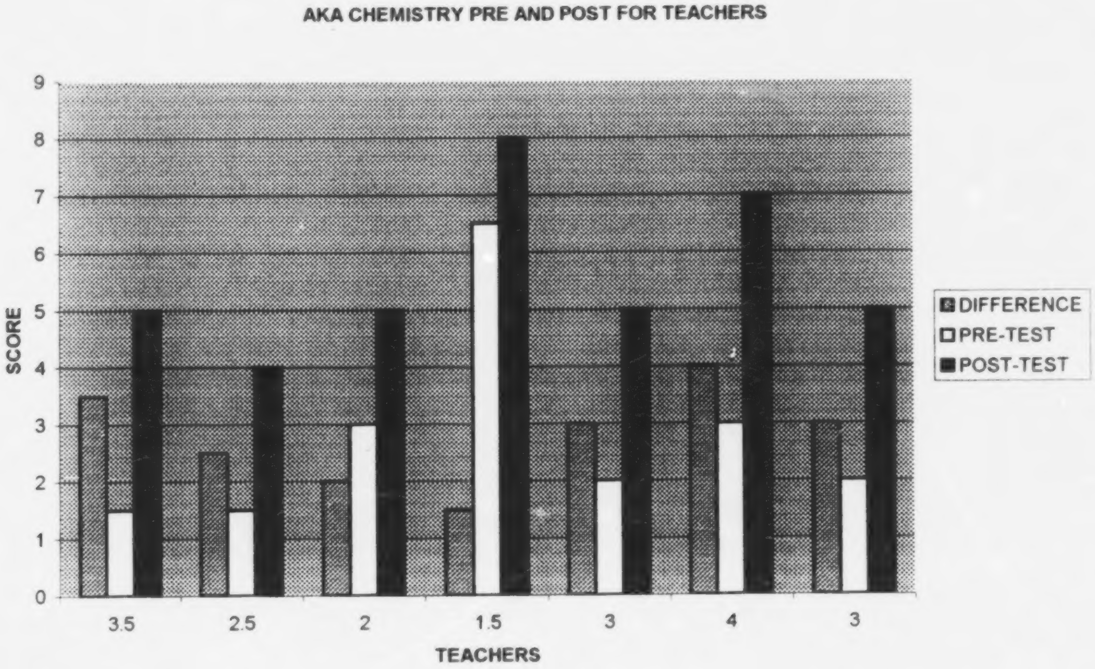

Figure 3. After-School Teachers' Content Test Results

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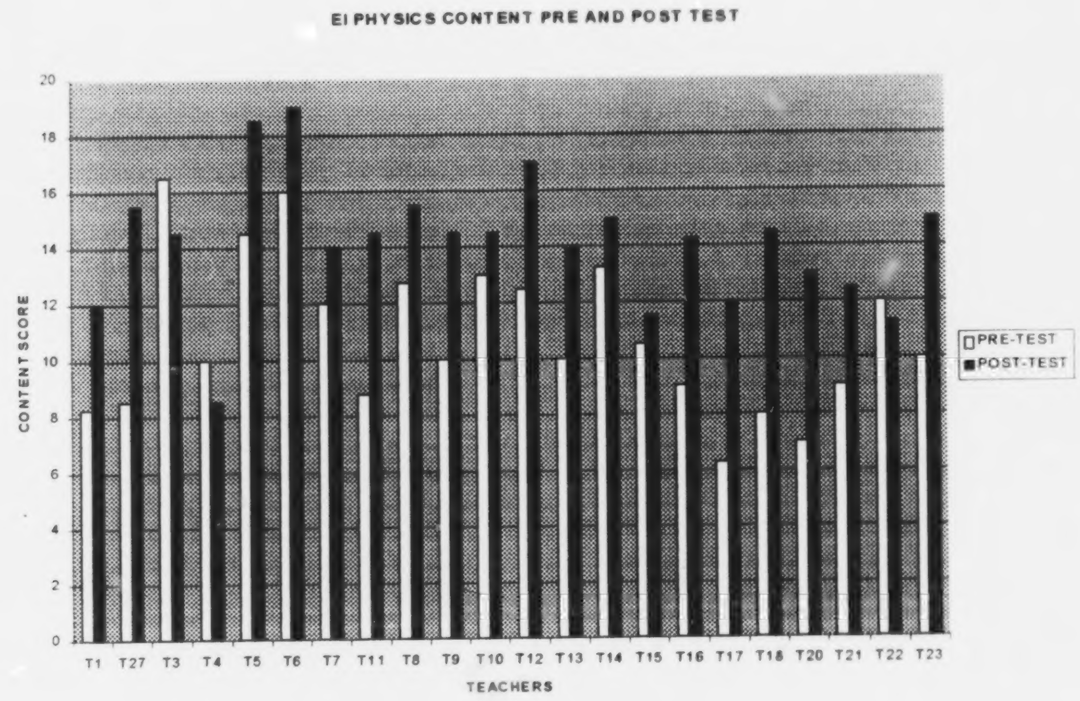

Figure 4. Summer Science Institute and Camp Teachers' Content Test

Participant evaluations of the summer science institute indicated that their expectations of learning science activities to motivate their students and how to manage and implement inquiry-based science in their teaching practices were more than adequately met.

I learned new ideas and extension activities for teaching science.

Learning new things to interest kids in science was invaluable.

The institute went well beyond what I hoped it would be.

Overwhelmingly, the participants indicated that the greatest benefits of the institute were the opportunity to work in partners and to try the experiments and lessons with small groups of children.

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...being able to try ideas experiments with children so I could make modifications and anticipate behaviors...

Collaborating with a partner, the exchange of ideas, and shared responsibility helped me to be more confident and made the experience more interesting.

I witnessed first-hand how children enjoy this way of learning.

The participants' views of science and science teaching were affected appreciably by their experiences.

The institute has given me an increased understanding and appreciation of how science can be taught.

Science seems less complex and fearsome. I have more confidence.

Teaching science is feasible, even in a class of 30.

It opened my eyes. There's not just one correct way to achieve a goal.

I am less fearful and more confident.

I was apprehensive before, now I look forward to teaching science.

I'm more open and feel more comfortable teaching using inquiry techniques.

Inquiry will cause me to use questions that cause students to think.

The participants indicated that their summer institute experiences influenced their views of how their students' understand and learn science.

They will remember what they have learned with hands-on learning.

Students can apply what they learn, not just spit out facts.

Students use a higher level of thinking than with worksheets.

The more than can "do" it, the more than can understand it.

The camp experiences showed me that students are smarter than I thought; they come up with ingenious ideas.

Hands-on will motivate students.

After working with the students, it is obvious to me that even lower achieving students can gain an understanding by using inquiry.

Safety and structure creates a deeper learning environment that fully engages students in learning.

Inquiry teaching/learning is not easy. My mouth wants to tell all, but I see students learn more and understand best if I allow them to discover. I have learned to ask questions leading to the answer rather than giving the answer.

All hands-on learning is not inquiry.

The teachers were asked to compare their perceptions of teaching and learning science through inquiry and note any changes from the beginning of the institute to the end of the institute.

I dreaded science before, now I see how much fun it can be.

Our experiences of using inquiry eased my concerns.

Implementing inquiry in my classroom may not be so difficult.

I feel more comfortable letting students do a lot of the learning process themselves.

I feel more comfortable about teaching by inquiry because we were shown how inquiry works and then we practiced what we learned.

All measures used to evaluate the pre-service and in-service teachers' beliefs and attitudes showed that they experienced improved confidence and attitudes toward teaching inquiry-based science and perceived its value for their elementary students' learning. Indicators also showed one of two things: (a) They were more likely to teach active, inquiry-based science lessons in their classrooms; or, (b) They indicated an intent to teach active, inquiry-based science lessons more frequently in their classrooms.

Discussion

The results of this study support the notion that the more experiences pre-service and in-service teachers have engaging in inquiry-based learning, the more positive the influence on their

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attitudes toward science and on their science teaching practices. Both the pre-service teachers and the in-service teachers indicated that their inquiry-based learning experiences raised their confidence to teach inquiry-based science and indicated an intent to teach more science by inquiry. Lesson observations revealed that the teachers were actually teaching more science by inquiry. This was likely influenced by their improved attitudes toward science and science teaching. Both groups of teachers indicated a discovery that teaching science is a viable and important endeavor in their elementary classrooms.

Journal reflections and course evaluations indicated that learning experiences were enhanced for both the pre-service and in-service teachers as they engaged in mentor/mentee situations. The pre-service teachers' knowledge of teaching was heightened by the relationships with the more knowledgeable, seasoned teachers. The in-service teachers benefited from the willingness of the pre-service teachers' risk-taking and openness toward inquiry-based teaching/learning, which was more closely aligned with the pre-service teachers' college learning experiences.

Among the implications of this study the three most important ones follow. This study suggests that open communication between faculty from departments of elementary education and faculty from the departments of science can have a strong influence on course development and scaffolding pre-service teachers' science content learning to their science methods courses in education and eventually to their pre-service field experiences and future teaching experiences. Early science learning experiences have long-term effects how elementary teachers perceive and teach science. In addition, partnerships between universities and school districts can enrich and continue education for in-service teachers. The shared responsibilities and the relationships developed through the professional development schools model of teacher preparation can have positive effects on science education in P-12 schools.

The systems within the larger system of education are complex, have a different character and appearance from one school to the next, and thus each requires communication, planning, and preparation by all entities involved. There is not a one-model-fits all systemic framework (Rodriquez, 2002). The nature of the professional development schools model, which is contingent upon partnerships, communication, and shared responsibility, can provide an environment in which unique and innovative decisions that advance systemic reform can be made on a school district by school district basis. Shared decision-making and responsibility has the potential for identification of needs and development of a system that will deliver equitable access to quality learning in science.

Further examination of this program and other similar programs will provide insight into their effectiveness to positively influence elementary student learning in science, into the sustainability of apparent changes in teacher beliefs, attitudes, and practices regarding science and science teaching, sustainability of institutional and public commitment to such programs, and into the long range effects of these programs on students' eventual choices and participation in challenging science courses in secondary and higher education.

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PROFESSIONAL DEVELOPMENT MODELS: A COMPARISON OF DURATION AND EFFECT

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Professional development has been a large part of the science education field for quite some time. Since the release of the National Science Education Standards (NSES) (1996), professional development in the form of in-service (or re-training practicing teachers) to meet both process and content science standards have burgeoned. The National Science Foundation (NSF) and much of the Dwight D. Eisenhower (DDE) money for higher education, as well as many other funding agencies and programs, have funded numerous national, statewide, and local programs.

With this increase in professional development have come scrutiny of previous professional development models. Traditional modes of professional development, "lectures to convey content and technical training about teaching" were criticized by the National Science Education Standards (NSES, 1996, p.56). Criticisms of professional development programs stem from as early as Karplus and Thier (1967), to numerous articles (Cook, 1994; Darling-Hammond & McLaughlin, 1995; Howe & Stubbs, 1997; Wallace, Nesbit & Miller, 1999), to entire books on the subject (Tobias, 1990; Mandy & Loucks-Horsley, 1999). Howe and Stubbs (1997) eloquently surmise the situation by stating:

> It seems clear that past and present methods and approaches to continuing professional development for teachers have not produced the desired result and that new methods and approaches are needed. If we continue to do the things we have always done, we will continue to have the results we have always gotten - and these results are not serving us well" (p.168).

The National Science Education Standards (1996) call for reform in professional development and "if reform is to be accomplished, professional development must include experiences that engage prospective and practicing teachers in active learning that builds their knowledge, understanding and ability" (p. 56). Although the NSES outline components that "Professional Development" programs should include, there is still a considerable amount of research in the literature on what and how professional development programs should be structured and conducted.

The literature reveals that many of the "new" forms of professional development have coincided with the rise of new programs such as Sci-Link (Anderson, 1993) , Project LIFE (Radford, 1998) and the GLOBE project (Pyke, 1999) to name just a few. Several models of professional development have been outlined as a result of these programs. Howe and Stubbs (1997) wrote about a constructivist/sociocultural model of professional development, Radford (1998) proposed a model of professional development in life sciences, and Wallace, Nesbit, and Miller (1999) wrote about six different leadership models in professional development that were developed by looking at 15 professional development programs over time in North Carolina. Additionally, several national organizations have recently made professional development a high priority and have been publishing books and information on professional development opportunities. The National Science Teachers Association (NSTA) has recently taken a lead in this arena and has set up a professional development network showcasing programs and offerings available from their website (www.NSTA.org). NASA has a unique "portable" approach to space education that they offer in a variety of locations for teachers. In addition, the National Science Education Leadership Association (NSELA) has recently published in concert with NSTA two new books edited by Rhoton and Bowers (2001). The first, *Professional Development:*

Planning and Design, and the second, *Professional Development Leadership and the Diverse Learner*. Both books are very informational and helpful in developing professional development programs.

All of these models have some commonalities; specifically, there was an intensive summer workshop ranging from two to three weeks, a project of some sort for the participants to work on, and academic year follow up. The programs included methodologies such as small group work, hands on activities, constructivist learning situations, and utilized scientists in the field content area of research. These are the components that good science instruction and professional development should include and are recommendations and/or suggestions advocated by the NSES (1996). Recently, the U.S. Department of Education (2000) released a three-year longitudinal study on professional development involved in the DDE program. It found basically no change in practice from teachers in the study. However, there were variances between teachers. When these variances were examined, they found that some professional development programs were more effective than others. The study identified "six key features of professional development that do improve teaching practice: Three structural features (characteristics of the structure of the activity) - reform type, duration, and collective participation - and three core features (characteristics of the substance of the activity) - active learning, coherence, and content focus" (p. 59).

Problem

For many years, professional development has been a large part of the science education community. Since the release of the NSES (1996), professional development in the form of in-service (or re-training practicing teachers) to meet both the process and content standards has intensified. The National Science Foundation (NSF) and much of the DDE money for higher education, as well as many other funding agencies and programs, have funded numerous national, statewide, and local programs.

The state of Nevada, like most other states, has recently written statewide science content standards, performance standards, and performance assessments requiring teachers teach certain concepts/topics by the benchmark grade levels. Performance tests for the children in their classrooms make teachers accountable for the science content taught. With this latest legislative action, some funding came from state appropriations in the legislative session, but the great majority of the retraining of the teachers still comes from entrepreneurial efforts related to diminishing funds from government agencies. With this influx of money and expansive base of initiatives, the question remains: Which workshops and programs with differing formats, and durations, of professional development, allows for the most productive results given the time constraints that classroom teachers already have with their busy schedules?

Purpose

The purpose of this research was to explore two professional development models, Nevada Operation Physical Science (a three weekend course) and Nevada Operation Chemistry (a two week intensive course with a follow-up session in the fall), to see if there was any impact on learning and the "ideal" length of the workshops as measured by teacher efficacy and outcome expectancy on teaching physical science. The general effectiveness of the program and teachers' perspectives on usefulness were anecdotal components of the study to help with discussion. In order to control variables, both workshops teach physical science concepts and were taught by the same instructors. Although some differences did occur between the workshops, for all intents and purposes the length of the workshop became the experimental variable. The population of teachers came from the same large county school district.

Program Description

Nevada Operation Chemistry

This research focuses on a national program that co-evolved with the Benchmarks, Project 2061, and the advent of the National Science Education Standards. Operation Chemistry (Op Chem) which was originally funded by the National Science Foundation (NSF) in conjunction with the American Chemical Society (ACS) was a five year effort that was designed to enhance the chemistry and chemical education literacy of teachers of grades 4-8 throughout the nation. Nevada Operation Chemistry, based upon the national Operation Chemistry model, is a program designed to enhance the conceptual and activity-related chemistry understanding of K - 8th grade teachers and pre-service teachers throughout the state of Nevada. Specific goals of the program are to (a) instill in participants a sense of confidence about their ability to learn and teach chemistry in a hands-on inquiry manner in accordance with National and State Science Education Standards; (b) foster professional growth, including presentation of content and methodology to peers in school, local, state, and national settings; (c) make participants aware of the relationship between chemistry in the school, university, community, and industry; (d) nurture the sense of community and collaboration among participants that is possible with an intensive, long-term program.

Nevada Operation Chemistry is a cooperative effort between the University of Nevada, Reno, College of Education, Chemistry Department, Biology Department and School of Medicine, Nevada State Department of Education (Science), Washoe County School District, Douglas County School District, Clark County School District, Humboldt County School District, Lyon County School District, The Nevada Rural Alliance, Newmont Gold Co., Cyanco, Eldorado Hotel-Casino, Brew Brothers, Nevada Mining Association, Women in Mining

Educational Foundation, and Sierra Nevada section of the American Chemical Society.

Nevada Operation Chemistry has been primarily funded by the DDE monies for higher education in the state of Nevada along with substantial donations from industry, businesses, and education associations totaling over $180,000.00 over the past three years and has trained more than 156 teachers.

The workshop is currently set up as a summer course where teachers are brought to the University of Nevada, Reno for a two week intensive workshop and field trip, a long term project/presentation to be made by the participant, and a follow-up workshop during the late Fall. Housing, per diem and mileage is provided for participants traveling from out of town. Tuition for graduate credit (3 credit hours) is paid by the program for all participants. In all, the two week workshop entailed 60 hours of formal instruction and a minimum of 11 hours of group discussion time.

The participants then go back to their classrooms and teach science adding Nevada Operation Chemistry activities to their current curriculum (which was part of the workshop of finding where and how the content and activities fit into their standards and curriculum). All the while they are working in teams of two to four in designing a professional development experience for teachers in their schools or districts. The professional development that they develop and teach is then shared at a follow up session (usually in late November) back at the UNR campus for an intensive one day follow up experience.

The total impact of Nevada Operation Chemistry (1997- 2000) to the State's teachers at well over 800 hours of instruction by our graduates (of the Operation chemistry program) to other teachers (teachers training teachers model) in inservice training and workshops impacting over 1600 people in over 53 different school settings in Nevada. Nevada Operation Chemistry workshops outside of Nevada have now impacted 12 other states, and over 1000 people. These numbers do not include the numerous hours of science teaching that takes place on a daily basis in each one of these teachers' classrooms

Primary instructors for the workshop involve college instructors (Education, Chemistry, Medical School, Biology), District Science Coordinator, industry scientists, classroom teachers, and graduates of the previous years' Nevada Operation Chemistry programs.

Based upon exit interviews and follow-up workshop discussions and presentations with participants from the past three years, Nevada Op Chem has been effective in changing pre-service and practicing teachers' abilities, attitudes and overall confidence in the teaching and learning of chemistry and general science in their classrooms. Science is being taught more frequently in the classrooms of our participants, thus resulting in better science test scores on exams and better grades in science. Two schools with concentrated teachers involved with the program have shown improved scores on standardized test scores school wide. Finally, the participants of Nevada Operation Chemistry are becoming more aware of environmental and industrial concerns and contributions in the state of Nevada.

Nevada Operation Physical Science (NOPS)

Nevada Operation Physical Science is a program designed to enhance the conceptual and activity-related physics/applied physics understandings of K - 8th grade teachers and pre-service teachers throughout Nevada. Specific goals of the program are to a) instill in participants a sense of confidence about their ability to learn and teach basic physics and physical science content in a hands- on inquiry manner; b) make participants competent users of the National Science Education Standards (NSES) and Nevada Science Standards and have participants achieve mastery of physical science (physics related) K-8 standards; c) foster professional growth, including presentation of content and methodology to peers in school, local, state, and national settings; d) make participants aware of the relationship between physics / physical science in the school, university, community, and industry; e) nurture the sense of community and collaboration among participants that is possible with an intensive, long-term program.

Nevada Operation Physical Science has successfully completed two years with 102 participants. The program was very successful in conveying content and pedagogy in the teaching and learning of physical science. Participants included pre-service teachers, elementary teachers, middle level math and science teachers, and a few high school teachers from all across the state of Nevada.

Nevada Operation Physical Science is a cooperative effort between the University of Nevada, Reno, College of Education, College of Engineering and the Mobile Engineering Lab (ME2L), Physics Dept., Chemistry Dept., Nevada State Department of Education (Science), Clark County School District, Douglas County School District, Humboldt County School District, Lyon County School District, Washoe County School District, The Northwest Regional Professional Development Program (Washoe, Pershing, and Storey counties), and the Reno Hilton. Nevada Operation Physical Science is an applied physics workshop covering content in mainly physics - but also covers the content in K-8 physical science standards not covered by Nevada Operation Chemistry I or II.

Nevada Operation Physical Science topics include: force and motion, energy and matter, light, sound, gravity, machines, electricity, magnets, space, and activities relating to the Mobile Engineering Lab (Solar Energy & Force and Motion) which can be brought to individual schools. This workshop was three weekends long beginning late spring. It ran from 12:00 noon to 8:00 PM on Fridays and 8:00 a.m. to 4:00 p.m. on Saturdays for three weekends.

Nevada Operation Physical Science follows the Standards Based, Hands-on Inquiry Model of instruction that is advocated by the National and State Science Education Standards. Additionally, as teachers complete the course, they will become trainers / instructors of other teachers and NOPS in following years.

Research Question

The duration of times of the workshop, Nevada Operation Chemistry (two weeks intensive summer workshop with a Fall follow up) and Nevada Operation Physical Science (three weekend sessions; one a month for three summer months) showed no significant differences on classroom teachers efficacy, and outcome expectancy, as demonstrated on the *Science Teaching Efficacy Belief Instrument* for in-service teachers (STEBI-A) (Riggs & Enochs, 1990).

Methodology

This study utilized a quantitative methodology. The employed design was a modified pretest-posttest design (Campbell & Stanley, 1963). The *Science Teaching Efficacy Belief Instrument* for in-service teachers (STEBI-A) (Riggs & Enochs, 1990) which was originally designed by Riggs (1988), to assess inservice teachers on two sub-scales: personal science teaching efficacy (PSTE) and science teaching outcome expectancy (OE).

The STEBI-A was administered on the first and last day of the two week intensive workshop for Nevada Operation Chemistry and then again four months later at the follow up workshop for Nevada Operation Chemistry. Again, the same instrument was administered on the first day of the first weekend sessions for the NOPS workshop and then on the last weekend of the NOPS workshop (approximately two months later).

The subjects included 47 practicing teachers from the 1999 Nevada Operation Chemistry program and 37 practicing teachers from the 2001 Nevada operation Physical Science program.

All participants are K-8 teachers from Nevada public school districts. Each of the workshops had non practicing teachers and pre-service teachers as additional participants in the workshops, but were not included in this study.

Results

Results of the Analysis of Variance (ANOVA) procedure on the Nevada Operation Chemistry STEBI-A PSTE scores, pre-post, were not found to be statistically significantly different. Outcome expectancy scores were significantly different and can be found in Table 1.

Table 1

Analysis of Variance of Nevada Operation Chemistry Outcome Expectancy Scores, 1999

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F
Between Groups	2	278.4816	139.2408	5.06	0.0083
Within Groups	90	2475.648	27.5072		
TOTAL(Adj)	92	2754.129			

(Groups: Pre-workshop, post-workshop, follow-up workshop)

Due to the significant results of the ANOVA, a Scheffe' Multiple Comparisons Test was performed upon the groups. Results of this procedure can be found in Table 2.

Table 2

Differences Between Pre-Post-Post STEBI-A Outcome Expectancy Scores in Nevada Operation Chemistry, 1999

Groups (A,B,C)	Mean	ABC
Pre-workshop (A)	42.02	. . S
Post-workshop (B)	44.63	. . .
Post-workshop (4 months later) (C)	46.28	S . .

Note: An "S" signifies a statistical difference at the .05 level.

Results of an ANOVA on the 2001 Nevada Operation Physical Science STEBI-A PSTE scores, pre-post, were also not found to be statistically significantly different, just as Nevada Operation Chemistry (see Table 3). Outcome expectancy scores, however, were found to be significantly different, albeit negative, and can be found in Table 4.

Table 3

Descriptive Statistics of Nevada Operation Physical Science PSTE and OE Scores, 2001

Variable	N	Mean	Median	St. Dev	SE Mean
PSTEpre	39	47.974	50.000	5.797	0.928
PSTEpost	37	46.35	46.00	6.33	1.04
OEpre	39	44.436	44.000	4.728	0.757
OEpost	37	42.919	42.000	4.734	0.778

Table 4

Mann-Whitney U Tests on Nevada Operation Physical Science OE scores, 2001

Group	N	Media
Oepre	39	44.000
Oepost	37	42.000

Point estimate for ETA1-ETA2 is -2.000

95.0 Percent CI for ETA1-ETA2 is (-4.000,-0.002)

Test of ETA = ETA Vs ETA not = ETA is significant at 0.0199

The test is significant at 0.0193 (adjusted for ties)

Discussion

This study revealed no difference in teacher efficacy in an intensive two week workshop with a follow up 4 months later as compared to a three weekend workshop over a three month period of time. There were some differences in outcome expectancy in both programs. The Nevada Operation Physical Science (three weekend course) had a drop in outcome expectancy over the time period of the workshop. This result seems to be compatible with other STAB research on professional development that does not include time for teachers to utilize activities in their classrooms. Although there was not a significant difference in outcome expectancy for the Nevada Operation Chemistry intensive two week workshop, there was a significant change in outcome expectancy after the follow up meeting four months later. This positive outcome expectancy change difference is maintained by the fact that the teachers had time to go back to their classrooms and practice the things which they learned during the intensive two week workshop along with working with peers to maintain this change.

Implications for this study include the notion that teachers do need intensive training in both content and pedagogy. However, to establish professional development that makes a difference in the classroom and in practice, more than the intensive workshop is needed. The difference in the Nevada Operation Chemistry group was that the teachers participated as a group from their schools. This lead to continued support throughout the school year as they had peers to work with and try out new ideas. The follow up workshop provided the motivation for the teachers to actually try out different labs and teaching practices so that they would have something to report to the rest of the group. As compared to the NOPS workshop which was three weekends during the summer (one per month for three months), most teachers taught on a traditional schedule and did not have the opportunity to try out activities and teaching approaches with their classes and no follow up requirement was included. Further analysis on extended outcome expectancy should be done for the NOPS group.

This all comes back to the question of what good professional development must include. The results of this study corroborate the findings of the U.S. Department of Education (2000) Longitudinal study and the suggestions from Gess-Newsome (in Rhoton & Bowers, 2001) in her literature review of good components of professional development that show specific things must be incorporated to have a successful professional development program. Amongst those recommendations are the duration of the course (with follow up), sustained support, collective participation and collaboration (with groups from the same schools for support), connections to classroom practices, utilizes content and pedagogy, promotes small changes over time, and involves active learning in all aspects of the professional development.

Further research must be done and shared with productive professional development models in science education. This study has shown that very little difference is made in two intensive weeks or three weekends, both of which are very popular models of professional development. A much more sustained and intensive program model is needed to demonstrate change in teacher efficacy and outcome expectancy is needed.

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TEACHER PROFESSIONAL DEVELOPMENT ACROSS STATES: LEVERAGING RESOURCES

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Project Goals and Objectives

The primary goal of this project is to deliver a Learning through Inquiry Science and Technology (LIST) professional development program to middle/elementary school science teachers of Madison County, Florida. Observers for this program, in a "train the trainer" design, will be faculty from the University of North Florida (UNF) who, in subsequent years, will use the LIST Model in their region of Florida.

Recent state and national reports verify the academic deficiencies of science students in this region of the country and call for changes in the way science is taught. The Nation's Report Card, released by then Education Secretary Richard Riley, tested the science understanding of students in grades four, eight and twelve. Florida students scored in the bottom 25% of students in the 40 states tested (Henry, 1997). In Florida, 49% of the students scored at the "below basic" science understanding level. Moreover, 95% of African American students and approximately 95% of economically disadvantaged students (based on free or reduced lunches) performed below grade level in science understanding.

According to 2000-01 Florida Department of Education data, the Madison County School System contains a high percentage of African Americans (57%) and students qualifying for free/reduced lunches (60%). The south Georgia and north Florida region contains a high proportion of minorities and students from economically disadvantaged homes. As a regional university of the University System of Georgia, Valdosta State University (VSU) services the academic needs of this area. VSU must reach out to the science teachers of this area to improve their skills if their students are to become productive and contributing members of local communities.

Important aspects of this project involve assisting middle school and elementary school science teachers of the Madison County School System to 1) become knowledgeable and effective with an inquiry based teaching procedure (learning cycle) which is consistent with both state and national science education reform efforts (GIMS, 1996; NRC, 1996); and 2) obtain the necessary experience and skills with instructional technologies to incorporate them into the inquiry based teaching procedure.

FL - LIST Model Activities

An Advisory Panel is responsible for the planning and implementation of the project. The Advisory Panel consists of a scientist, two educational technologists (one each from VSU and UNF), a certified Teacher Support Specialist, four science teachers, and two science education professors (one each from VSU and UNF). The project includes three phases. The first phase of the project, Exploration Phase, is designed to allow the teacher participants to experience the learning cycle teaching procedure, explore its theoretical underpinnings and participate in the operation of a variety of instructional technology equipment. The second phase, Application Phase, is designed to allow teachers to construct learning cycles, integrate technology into their curricula, and use these lessons with their students. The third phase of the project, Follow Up Phase, is one in which teachers continue to apply the new found information and skills in their science classrooms with continuous support from project staff.

I. Exploration Phase

Twenty (20) middle school and elementary school science teachers from Madison County, FL are participating. For one week in the summer these teachers met four days from 9am to 4pm at Madison County K-8 School. Each day was spent in laboratory sessions led by members of the project team (inservice teachers, scientist, education technologist, Teacher Support Specialist). These sessions included technology laboratories, designed to familiarize teachers with the use of a variety of educational technologies (e.g., computers, video technology) and how to incorporate these into their curricula; and science laboratories modeling the learning cycle teaching procedure led by inservice teachers experienced in the inquiry teaching procedure.

An important point to be made here is that each learning cycle investigates (an) important and easily recognizable scientific concept(s). That fact permits the teachers in the workshop to review science content while they learn how to teach that content using learning cycles. A scientist is on staff to monitor the accuracy of the science content taught through the learning cycle demonstrations and act as a science content reference for the remainder of the staff and teacher participants.

This phase of the project requires teachers to meet with project staff at least 30 hours over the five-day period.

II. Application Phase

This phase began after the first two weeks of the start of school in August 2001. Teacher participants met with project staff every alternate Saturday for 8 weeks from 9am to 1pm (four total sessions over an eight-week period). These meetings took place in the media center at the Madison County K-8 School.

During the Application Phase, teachers received a copy of the learning cycle science curricula of their choice - biology, chemistry, physics, general physical science, life science, earth science. In addition, all teachers brought their current science curricula so that they may use the learning cycle curricula as a model to integrate with their science curricula. During each of these sessions, teachers in partnership with each other and the project staff, modified two weeks of their science curricula into inquiry based lessons. Successes/difficulties associated with implementing these inquiry-based curricula in their own science classrooms were discussed.

This phase of the project required teachers to meet with project staff at least 20 hours over the four meeting days. Communication with staff members, such as the scientist for questions pertaining to content, was encouraged through the use of electronic mail.

III. Follow Up Phase

The Follow Up Phase will occur through the remainder of the fall semester and throughout the spring semester. The Exploration and Application Phases of the project allow teachers to accommodate the inquiry based curricula and its theory base; but sound understanding comes with using the learning cycle in their science classrooms during the ensuing school year. Therefore, follow up meetings will be a significant part of the project proposed here and will occur in many forms.

A member of the project staff will observe each teacher in their classroom two times during the Follow Up Phase. These observations may occur once during any time negotiated with each teacher. Following each observation will be an individual meeting between the teacher and staff member to discuss the implementation of the inquiry teaching procedure, incorporation of technology, assessment, or other factors associated with the curricula or of concern by the teacher.

In addition to these individual observations will be two meetings with all teachers and project staff members to share successes/difficulties and to brainstorm solutions to problems any teacher may have encountered. These meetings will take place after school from 3-5pm once in February and again in April.

It is estimated that the follow up part of this project will result in at least 12 hours of contact time between each participant and the project staff. Total contact time with each teacher over the course of the project will be at least 60 hours.

Evaluation

Baseline data

Self-report questionnaires surveyed participants about classroom practices and technology skills prior to implementation. This information was used to establish a baseline in inquiry approaches to teaching and technology skills and integration.

Prior to the project, teaching methodology by the participants could be classified as traditional. Teacher lectures, student reading, worksheet completion, videos, and demonstrations accounted for nearly 75% of instructional time.

Technology usage was also very limited with the computer and VCR being the only technologies incorporated into the classroom about 5% of the time. Teachers indicated a high level of anxiety for technology utilization in the science classroom. However, they also expressed a general interest in learning how to use new software or technologies.

Preliminary findings

Self-report surveys, participant written reflections, and analysis of lesson plans are being used to examine classroom practices and technology skills integration during the midpoint of this project. Data are currently being collected, however, preliminary findings suggest much greater use of inquiry-oriented teaching strategies, increased use of technology in the science classroom, and renewed interest in science teaching. These teachers are also reporting their students have a greater interest in science, lower off-task behavior, better test performance, and more positive interactions with teachers. Further data collection and analysis must occur prior to making final conclusions concerning effectiveness of the project.

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TIME TO LEARN: A SUCCESSFUL K-12 SCIENCE EDUCATION PROFESSIONAL DEVELOPMENT MODEL

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Time to Learn (TTL) is a professional development model that evolved from eight years of collaborative effort among scientists, science educators, and area teachers to design effective and locally meaningful experiences for educators in Northwest Wisconsin. During planning meetings and ongoing outreach activities, teachers consistently expressed need for time to work on reviewing and developing resources, need for networking, support for redesigning curriculum to meet standards, and opportunities to receive focused one-on-one or small group content instruction as important variables for improving their practice. These conversations lead to a series of extended professional development activities supported in part by the Dwight David Eisenhower Foundation. Initial projects focused on elementary and middle level teachers. The current project focuses on the needs of 6-12 teachers. The following discussion illustrates the need for designing professional development with teachers' views in mind, and presents a model for an evolving professional development program that provides teachers with time, relevant instruction, and resources to achieve realistic changes in practice.

Why should we think differently about Science Staff Development?

Reports from professional science organizations, teacher professional development literature, and policy agencies consistently call for changes in thinking about curriculum, teacher preparation, and professional development (American Association for the Advancement of Science, 2001; Garret, Porter, Desimone, Birman, & Yoon, 2001; Loucks-Horsley, Hewson, Love, & Stiles, 1998; National Research Council, 1996). The National Science Education Standards (NSES) note: "The current reform effort requires substantive change in how science is taught; an equally substantive change is needed in professional development activities" (NSES, 1996, p. 56). Key facets of this philosophy are highlighted in Teaching Standard B, which emphasizes the need for inquiry experiences, and Professional Development Standard B, which focuses on the need for teachers to integrate knowledge of science and teaching, in order to enhance student learning. Science professional groups such as the American Chemical Society, the Geological Society of America (Havholm, 1997), and the American Physical Society support such efforts by supporting K-12 partnerships and sponsoring forums on science education during their technical sessions.

Societies of professional scientists are keenly interested in helping science teachers improve their knowledge and teaching. For example, the Education and International Activities Division of the American Chemical Society offers professional development workshops for teachers as well as continuing education for practicing chemists. A variety of learning formats is available, including in-person workshops and courses, as well as programs delivered via the Internet. Programs are available at all levels: elementary school (Inquiry in Elementary Science), high school ("ChemCom" workshops), college ("Chemistry in Context" training, Preparing Future Chemistry Faculty), and continuing education. The American Geological Institute supports professional development for teachers through Curriculum Leadership Institutes, Teacher Enhancement Workshops, and the Web-based Teacher Enhancement Program. Their programs are typically two to five-day sessions designed to train new teachers through inquiry-based experiences that model effective teaching strategies, promote community awareness, and foster leadership. The American Geophysical Union works closely with Chairs of Earth and Space Science Departments to improve science education through workshops, electronic education briefs, research grants and awards, and student travel awards. They also worked with the Keck Geology Consortium and five divisions within the National Science Foundation to convene a workshop in 1996 to define common education goals among all disciplines in Earth sciences. The proceedings, "Shaping the Future of Undergraduate Earth Science Education," were the first disciplinary response to NSF's initiative on the subject. In August of 2001, the American Physical Society (APS), in partnership with the American Association of Physics Teachers (AAPT) and the American Institute of Physics (AIP) established PhysTEC, the Physics Teacher Education Coalition. PhysTEC aims to dramatically improve the science preparation and teaching skills of future secondary and elementary teachers and to establish an Induction/Mentor program for new teachers to improve the likelihood they will remain in teaching.

Discussions of teacher professional development (e.g., Coble & Koballa, 1996; Sparks & Loucks-Horsley, 1989) identify successful models and change processes including the development of community, encouraging innovation and risk-taking, identification of worthwhile incentives, collaborative design, and time for reflection. Garret et al (2001) indicated that professional development that is content-focused, connected to other aspects of teachers' lives, and coherent is more likely to have positive impact on teachers' knowledge and skills than less coherent experiences and that coherent changes positively impact teaching practices. Further, differences between the impacts of traditional workshops and reform activities such as study groups were linked to ways time was used (long-term experiences with many hours of contact resulted in greater gains in knowledge and skills), but were not direct outcomes of the type of activity. Loucks-Horsley et al (1998) highlighted seven principles of effective professional development:

- Beginning with a well-defined image of effective classroom learning
- Creating opportunities to build knowledge and skills
- Modeling strategies that teachers will use with students
- Establishing a learning community
- Supporting teachers as leaders
- Linking professional development to other parts of educational systems
- Self-assessment of programs by the professional developers themselves

Staff development that meets teachers' needs and which makes a difference in their classrooms remains an elusive goal. The 2000 National Survey of Science and Mathematics Education (Weiss, Banilower, McMahon & Smith, 2001) indicates that less than 25 percent of teachers in grades K-8 have spent four or more days in professional development related to these. Respondents identified funds to purchase resources, time to plan and work with other teachers, and time for professional development as serious problems. However, less than one-third of the respondents indicated that professional development experiences actually matched their perceived needs. Two thirds of the respondents who actually participated in science and mathematics-related professional development indicated that they did not change their teaching practice as a result of the experiences.

The current TTL model highlights the recommendations of the NSES and the dimensions of professional development described above by blending early planning, team building and goal setting, self-directed intensive summer professional development, and classroom implementation and evaluation of standards-based curriculum, teaching and assessment practices into a coherent experience applicable to teachers at all grade levels. The TTL model is developed in detail below.

What is the Time-to Learn Model?

The time-to-learn model is designed to provide participants with support for focused changes in their professional practice. It emphasizes purposeful diversity in staffing, explicit emphasis on research-based practices, and extended blocks of teacher-directed learning. The TTL model is grounded in the belief that educators, like other professionals, are able to identify areas in their own practice that need improvement, and when provided with time and support, will make significant improvements in their teaching. The TTL model evolved through a series of collaborations among scientists, science educators, and K-12 teachers. Figure 1 below illustrates the three components of the TTL model. Each of the components is developed in detail in the sections following the diagram.

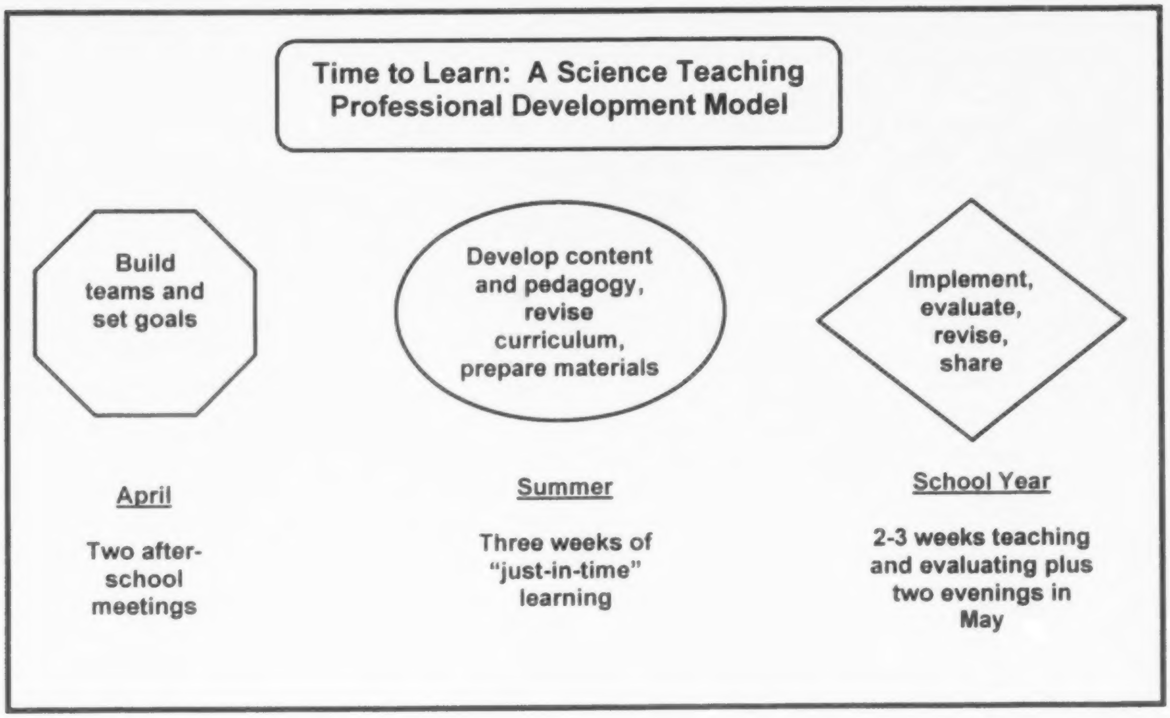
Time to Learn: A Science Teaching Professional Development Model
Build teams and set goals
Develop content and pedagogy, revise curriculum, prepare materials
Implement, evaluate, revise, share
April
Two after-school meetings
Summer
Three weeks of "just-in-time" learning
School Year
2-3 weeks teaching and evaluating plus two evenings in May

Figure 1. The TTL Professional Development Model

PESTO: An Example of the TTL Model

PESTO (Physical and Earth Science Teaching Opportunities) is the latest application of the TTL model. It is significant because it is a successful adaptation of a model developed through work with elementary teachers to meet the needs of middle and high school teachers. During PESTO, the "on-call" staff included a geologist, a physicist, a chemist, a science educator with middle/secondary teaching experience, a middle school earth science teacher, and a high school science/math teacher – former NASA engineer.

Building teams and setting goals. PESTO began with two meetings in the spring of the school year. The purpose of the meetings was to establish goals for the project, and begin developing a sense of community among the participants. The first meeting highlighted the philosophy and program design and engaged participants in reflection and brainstorming about their own professional development goals. PESTO staff (scientists, science educators, and teachers) shared their own interests and expertise and reviewed the resources available for use. The meeting was critical for two reasons. First, it initiated the planning process by asking teachers to reflect on their curriculum and teaching and determine for themselves the areas in need of attention. Second, it alerted teachers that their existing expectations about "workshops" would not be the norm for the project. By stressing the self-directed format of the project and making expectations for products and work clear at the very first meeting, we helped teachers determine whether this program was really for them. At the same time, the meeting alerted participants to the idea that the project staff would be deliberately structured to meet their needs, and would include scientists with appropriate backgrounds, at least one science educator with extensive teaching experience, and one or more teachers from the region who were recognized for their expertise in teaching.

The second spring meeting emphasized group-building activities, clarifying and sharing goals, developing project objectives, and starting a list of activities and project resources. The second meeting also included an opportunity for teachers to work together to clarify ideas and leave with a clear sense of purpose about their summer work. The information helped the PESTO staff gather resources, hire K-12 consultants, and plan sessions specific to the teachers' goals.

Developing content, pedagogy, and materials. The summer workshop occupied 18 days in June. We required attendance for the first three days, the last day, and on three other "check-in" days. Eleven days were deliberately left unscheduled; the participants used the time to work in small groups, plan and complete field trips, consult with project staff, and worked towards the goal of having their revised curriculum and materials in "ready-to-teach" form at the end of the three weeks. In addition to the check-in days, PESTO staff required participants to keep a log demonstrating at least 60 hours of goal-directed activities. Teachers were trusted and expected to make appropriate use of their time. The designed free time feature provided flexibility and freedom for teachers with family responsibilities, and enabled participation by individuals enrolled in other activities that overlapped with PESTO. The following "outline" illustrates the flow of the summer session.

Week #1 (3 days, Wednesday – Friday): The workshop began with activities and discussions on the national and state standards, the nature of inquiry in science and in teaching, and standards-based assessment. These sessions modeled inquiry-based constructivist practices through projects involving the chemistry of a rusty nail, "designer" acid-base indicators, weathering, pendulum motion, and the physics of a "full-length" mirror. The projects served as references for discussions about learners and learning, technology integration, curriculum, instruction, classroom management, and assessment. Teachers spent half of each day refining their professional development goals, organizing work groups, and building relationships with other participants and staff. On Friday, each group submitted a written and oral topic description, identified needed resources, and sketched out a manageable work plan.

Weeks #2 - #4 (Monday – Friday): The teachers began putting their project plans into practice. A project room was available from 8:00 a.m. to 4:00 p.m. PESTO staff scheduled content sessions, helped locate resources, facilitated discussions of science teaching best practices, modeled technology use, and organized visits to community- and field-based resources. Teachers worked at home, at their schools, organized field trips, learned to use new equipment, designed materials, and perused resources in the project room. The "just-in-time" learning, though sometimes cumbersome to manage, provided focused support and feedback when the teachers decided it was needed. On check-in days, teams met with assigned PESTO staff. The short sessions provided some informal progress accountability, increased communication, and helped the PESTO staff keep abreast of the teachers' needs. On the last day of the summer session, each team assembled a 15-minute report that detailed goals accomplished and tasks remaining before the school year.

Implementing, revising, and sharing. During the following school year, PESTO teachers implemented and evaluated their projects and made revisions based on student performance. Although resources were available for releasing teachers to work together, provide peer observation and coaching, few participants used the time. PESTO staff kept in contact through emails, a project web site, and informal visits to classrooms. Each team was required to gather evidence of improvements in student learning, and to meet to revise their projects after they implemented them for the first time. A final portfolio, including examples of student work and revisions based on classroom evaluations, was completed and shared in an evening meeting in May. Each team presented the revised curriculum and materials, discussed the successes and limitations of their approach, and discussed further improvements with the PESTO staff and other teams.

Discussion

The PESTO example highlights the overall nature of the TTL model. Clearly, such a model is not without limits nor does it function without incentives. Participants received a stipend of $150.00, tuition support (as a University matching donation) for two graduate credits during the summer and one additional credit for completing the implementation, evaluation, and revision. Each team received reimbursement for about $150.00 for project materials. In addition, each participating school was required to commit $300.00 per teacher to support the project (funds did not leave districts but their use was directed by the teachers). By combining different resources, the TTL model resulted in approximately $500-600 in additional financial support for science resources per school building (which in many cases exceeded the regular science budget).

An ongoing challenge for the TTL staff is documenting impact on student learning. Currently, we rely on teachers' reports and anecdotal evidence of improvements in student learning. Evaluation data (discussed later in this paper) suggest that important improvements in practice, attitudes towards science and science teaching, and professional efficacy are occurring as a result of the TTL approach. In a few instances, participants have been unsuccessful in managing the time and responsibility to produce tangible, defensible improvements in curriculum, teaching strategies, and materials. While we have successfully engaged teachers in extended experiences that address needs identified within the group, the sense of community that begins during the summer doesn't sustain itself through the school year.

The following section illustrates the evolution of the TTL model from a structure that was highly instructor-driven towards the collaborative model that currently exists. The history illustrates some lessons learned along the way, the emergence of trust, and the increasing collegiality among university and K-12 educators in the design and implementation of the model.

Evolution of the Time to Learn Model

A series of summer workshops with follow-up activities has been held since 1993 that lead to the evolution of the TTL model. Each of the workshops engaged area K-12 teachers in about three weeks of work. The grade levels taught by the participating teachers changed and the instructional staff varied from year to year. However, enough continuity existed to enable the goals and structure of the workshops to evolve with lessons learned in previous years guiding and improving subsequent activities. Each of the workshops and their contribution to the TTL model are described below and are summarized in Table 1 at the end of this section.

CUBE 1 and 2 (Make and take, but teachers want more)

The first workshops were presented under the name Coalition of University and Business for Education (CUBE). CUBE 1 was a three-week summer workshop for 30 K-5 teachers where they learned about teaching hands-on science on the themes of water, trash and outdoor education. CUBE 2 hosted a new group of 25 teachers and followed a similar format. The workshops were presented by science faculty from the UWEC Chemistry (Dr. Eierman), Geology (Dr. Hooper), Biology (Dr. Brakke) and C&I (Dr. Hollon) departments. Three local K-12 teachers helped develop and present some of the material. Four UWEC student teachers were also hired to help organize, present, and support the activities. Twenty-three different people from the university and community made science and technology presentations. Three tour days were held in which participants visited six local facilities to observe science and technology in action.

Strong efforts were made to give teachers the knowledge and the materials needed to put hands-on science activities into their classroom teaching. Teachers were presented with a three ring binder describing many of the hands-on activities seen in the workshops. In CUBE 2, a CUBE box, filled with every sort of material or device necessary to carry out the science activities, was also given to each school in the Eau Claire school district. Participants were also given funds to purchase science supplies. Teachers earned two graduate credits for participation in the workshop. These were classic make-and-take workshops, emphasizing hands-on science activities that could be presented and stored conveniently in the elementary school setting.

The evaluations consisted of a pre- and a post-survey completed by the teachers on the first and last days of the workshop. We have also received anecdotal, informal feedback. Teachers indicated no change in their perception of their knowledge of science compared to other fields and strong agreement that hands-on science is harder to teach, but more meaningful to children than textbook science. Teachers showed a significant gain in their confidence in teaching hands-on science and a large increase in their knowledge of local science resources outside the classroom. Participants indicated that the CUBE workshops met their expectations, that the presenters were knowledgeable and effective and that there was ample opportunity for interaction and collaboration.

Participants were asked, "What additional ways can the university, the school district and local business collaborate to improve classroom science instruction?" Responses included: *give teachers time and resources to develop curriculum*, increase funding for science (materials), have university students visit the classroom to present science, continue CUBE, provide teachers with speaker lists, and have business and university people visit the classrooms to find out what is happening there. We considered these issues as we developed CUBE 3, which was structured to provide teachers with support and time to design science curricular materials.

CUBE 3 (The teachers choose the topics)

CUBE 3 represented a significant departure in terms of organizational structure. 23 K-5 teachers worked in teams over three weeks to develop hands-on science curricular materials for use in their teaching. Four faculty members and one local elementary teacher served as instructors, helping teachers in their development activities. Teachers chose their own topics to work on and were provided with a variety of resources during the development activities. Teachers gathered and modified written materials and supplies, e.g. collections of different types of locally occurring rocks. Each group wrote and submitted a curricular package and presented an oral report on the materials that they developed. Teachers were provided funds to purchase supplies during the workshop and in the following school year and they earned one graduate credit for participation in the workshop. Teachers were also offered funds to pay for substitutes so they could visit each other's classrooms during the following school year.

CUBE 3 achieved its goal of enabling teachers to develop skills and materials to teach science more effectively. Because the teachers chose the topics with feedback from the CUBE instructional staff, the developed materials had a high potential to be used immediately. The role of the instructional staff was to help the teachers find and understand information that was pertinent to teaching the chosen topics. Many of the teachers had participated in CUBE 1 and 2 in which they were shown and given a wide variety of science materials. In CUBE 3 they customized and organized those materials to fit into their lessons. Most teachers enjoyed the opportunity to control the topics and activities they engaged in during the workshop. Anecdotal information suggests that the teachers really used the written materials and supplies they gathered. However, no teachers visited other classrooms during the following school year. Teachers did not find time for this and hesitated to request substitutes.

TEES (Teachers develop standards-based earth science curriculum)

Teaching Elementary Earth Science (TEES) was attended by 25 K-6 teachers interested in earth science. Two faculty members and one local middle school teacher served as instructors. The teachers worked in groups on development of earth science curricular materials. The instructors presented content sessions on requested topics of interest to the teachers and as they made the presentations they utilized teaching methods consistent with the National Science Education Standards (NSES). In addition, the instructors lead the participant teachers on a variety of local field trips, during some of which the teachers collected geologic samples of interest. Teachers also visited the middle school classroom of the one of the instructors to see his collections and displays. Teachers did curriculum development work on campus as well as at other sites.

Teachers presented their curricular materials in an oral report to the whole group at the end of the workshop. They implemented their new materials during the following school year. At the end of that year, the teachers returned for two days to complete their projects and make a final oral report regarding the success of their new materials and submitted a written report that included a copy of their revised curricular materials. Teachers were provided funds during the workshop and the subsequent school year to purchase supplies and they earned three graduate credits for completion of the workshop.

Surveys of teachers following the implementation of their new curricula showed that they utilized more hands-on and inquiry activities and that they felt more enthusiastic and confident in their teaching of earth science. They were pleased to have more resources both in the classroom and in the local community to use in their instruction. Teachers also reported that their students learned earth science more willingly and in greater depth. Teachers were pleased to have witnessed the workshop instructors teaching according to the Standards. Other conclusions from TEES are that teachers need to be aware of the expectations on them to develop curriculum (some teachers weren't comfortable with the independence), that at least one credit should be held until the final report is submitted and that two days were too much for the follow-up session. Once again, no teachers took advantage of the opportunity to visit a classroom of their peers.

STEPS (Teachers develop methodology and content)

The Superior Teaching of Elementary Physical Science (STEPS) workshop was attended by 26 K-6 teachers, while four faculty members and a local middle school teacher served as instructors. The goal of the workshop was to enable teachers to improve their teaching of physical science at the elementary level by showing teachers some models of science teaching methodology, teaching them some physical science content and giving them time and resources to develop self-chosen physical science curriculum units. Teachers were encouraged to tie their teaching methods and content to the Standards (NSES, WMAS). The teachers utilized their newly developed science units in their teaching during the following school year and engaged in some follow-up activities in spring at which time each group submitted a complete packet of tested science curriculum materials.

The three-week workshop consisted of three phases. During the first three days, the participants worked together in small groups to experience inquiry-based science activities. These activities demonstrated ways to present science as a process in which the learner is actively engaged. Teachers investigated rusty nails, built small machines that have specified characteristics, investigated pendulums and developed a model explaining the behavior of three-layer carbon paper. The teachers also formed groups and chose a science topic to develop. They chose a theme, goals, products and content questions, prepared a written work plan and made a presentation to the whole group

The second phase lasted for most of the rest of the three weeks. The instructors planned and presented content sessions on requested science topics to interested participants. The optional science presentations were at a high school or introductory college level. Several field trips were also taken during the workshop to give teachers real-world context for science and technology in their teaching. The remainder of the time was spent by the participants developing their curriculum. Each group established its own schedule and method of developing their materials. Work was done in a workshop classroom, but much occurred in other locations such as the library, the teachers' schools or at home. Teachers also gathered science supplies using workshop funds.

The final phase of the workshop occurred on the last day when teachers shared the curriculum they had developed. Each small group made a 5 to 10 minute presentation describing their curriculum and the connection to the Standards. Each teacher also demonstrated one hands-on activity to the other teachers. Teachers were also provided with funds to purchase supplies during the following school year and they earned two graduate credits for participation in the workshop and one more credit for completion of the final reports the following spring.

The following spring two additional sessions were held. The purposes of the first meeting were to reestablish the communication lines within the group, to get an update on progress the participants were making in implementing their materials and to plan the follow-up activities for the rest of the spring. At the second meeting each participant group made a 15-minute presentation on their project summarizing the curricular materials and described their implementation. A great deal of testimony was presented regarding how the new materials changed the in-class experiences of the participant teachers and their students. Teachers also submitted their final reports, which consisted of a package of curriculum materials, a reflective report from each individual and an exit questionnaire.

The participants said that they were able to use the workshop time to initiate changes in the way they teach science. They were appreciative of the time, freedom and support to move in a new direction. One participant said, "Change has to keep happening, but it is very time consuming. This workshop gave us the time to make changes." More than half the participants felt that having time to plan and prepare and having a chance to collaborate with professors and other teachers were the most valuable parts of STEPS. About half said no changes in the format of STEPS are needed but several said that more specific goals, more on-line experiences and more "progress checking meetings" during the year would make STEPS more helpful. All of the 19 participants who responded said that the STEPS program was very effective.

PESTO 1 and 2 (The model is extended to middle and high school)

The TTL model was next extended to middle and high school teachers. A first attempt at getting funding was unsuccessful when reviewers felt there was too little material being "taught" to the teachers. A second proposal explained the TTL model better and was funded. Two "Physical and Earth Science Teaching Opportunity" (PESTO) workshops have been attended by 14 and 28 middle and high school science teachers. Four UWEC faculty members served as instructors for the workshops. The format of the workshops was very similar to that of STEPS. Following a couple of days of meeting in which the instructors modeled inquiry-based teaching, the teachers chose and wrote a proposal describing a topic and materials that they would develop. During the next three weeks the teachers worked alone or in groups to develop materials with the help of requested content presentations and field trips, run by the instructors. Each teacher logged at least 60 hours of work in completing his or her development activities (some were as high as 120 hours). Each individual or group presented their project, including links to the WMAS, at the end of the workshop and implemented it in their classroom the following school year. In the spring, the teachers returned to present a final report on the successes and failures of the new curriculum to the group. Teachers were provided with funds to purchase supplies during the workshop and during the following school year and they earned two graduate credits for participation in the workshop and one more credit for completion of the final reports the following spring.

PESTO participants greatly valued the time and resources to develop their knowledge and curricula. They also valued being treated as professionals and colleagues by the instructors. They enjoyed seeing the model teaching, which helped them to understand what inquiry-based instruction means. Several of the participants utilized the actual example lessons in their own teaching during the following school year. Teachers also said they focused more on student's prior knowledge when teaching following the workshop. Teachers said they learned content and changed their pedagogy because of PESTO. The 6-12 teachers worked in more smaller groups or alone than their K-6 counterparts. For this reason, less of a community developed during the course of the workshop. In addition, some teachers seemed to need more check-in times during the workshop to help them keep on track. During PESTO 2, more whole group sessions and more check-in days were scheduled to help alleviate these situations.

In conclusion, the application of the TTL model to middle and secondary teachers is seen as successful. Teachers were very positive about the opportunity that these workshops offered and many requested that more such workshops be held to enable them to continue their professional development in a format that provides them what they need.

Table 1. Evolution of the TTL Model

Workshop (Grade level)/Year *Instructors*	Format of Workshop *Follow-up Activities*	Conclusions	Improvements For Next Workshop
CUBE 1 & 2 (K- 5)/1993, 94 *Eierman (Chem)* *Hollon (C&I)* *Hooper (Geology)* *Brakke (Biology)* *3 Teachers*[•]	Mostly hands-on science activities (make and take). Tours of local facilities utilizing science & technology *No follow-up*	Teachers gained confidence in teaching hands-on science and found resources in the community. Also gathered materials and supplies	Give teachers time and resources to develop curriculum. Teachers want classroom visits for presentations and observation.
CUBE 3 (K - 6)/1995 *Eierman (Chem)* *Hollon (C&I)* *Hooper (Geology)* *Brakke (Biology* *L. Christ*[•]	Teachers developed curricular materials with guidance. Groups presented at workshop end. *Peer visits supported.*	Teachers used new materials and supplies in their teaching. Time to develop materials was valuable. *No peer visits used.*	Help teachers with science teaching methodology. *Improve follow-up sessions.*
TEES (K - 6)/1997 *Havholm (Geol)* *Hollon (C&I)* *Varsho*[•]	Teachers developed curriculum on-campus, added field trips and classrooms. NSES highlighted. *Teachers implement and report. Peer visits offered.*	Teachers improved hands-on activities, enthusiasm, confidence and inquiry. Students did more inquiry, were more motivated. *Follow-up helped. No peer visits used.*	Present model teaching. Screen participants. Not 3 cr. in workshop. *Abandon visitations.* *Don't need 2 follow-up days*
STEPS (K - 6)/1998 *Havholm (Geol)* *Eierman (Chem)* *Hollon (C&I)* *Hendrickson (Phys)* *Fredrickson*[•]	Inquiry-based teaching modeled and critiqued. Teachers identified content focus for curriculum development. *Teachers implement and report. 2+1 credit model used.*	Teachers value time and resources to change. Model teaching helped them understand inquiry. Groups functioned well. *Follow-up effective.*	More progress checking during follow-up.
PESTO 1 & 2[+] (6 - 12)/2000-01 *Eierman (Chem)* *Hollon (C&I)* *Hendrickson (Phys)* *Havholm (Geology)*	Similar structure to STEPS but with 6 - 12 teachers.	Teachers value time and resources to change. Model teaching helped them understand inquiry and rethink content.	Groups smaller. Need different ways to foster community. 6 - 12 teachers are more independent than K – 6 teachers.

[•] Indicates K-12 teacher.

[+] A proposal to fund a PESTO workshop in 1999 was not funded because reviewers felt there was not enough material being presented to the teachers.

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How Does The TTL Model Impact Teachers' Thinking And Classroom Practice?

"I came because it was free. I stayed because it was good!" That quote by a participant reflects teachers' responses to the TTL model. Our evaluation data consistently indicate that teachers perceive TTL as professionally empowering and making a significant impact on their practice (Hollon, Eierman, Havholm & Hendrickson, 1999). One hundred percent of the participants for the past two years (N=42) indicated that they would participate again and would recommend it to other teachers. Responses to open questions about changes in thinking about science, teaching, learning, and assessment show a range of impacts. Money, credit, and other financial incentives were not identified as most significant, while time, freedom to work, and networking were listed most frequently as positive aspects. Some teachers found the freedom challenging and wanted more external control of their time, especially when many trips, small group sessions, and resources were available (Eierman, 1999; Havholm, 1998; Havholm & Eierman, 2000).

Evidence of Impacts of the TTL Model

Data describing the impact of the TTL model come from two main sources. Teachers involved in the professional development programs (CUBE, TEES, STEPS, PESTO) reflected on changes in their own content understanding, their ideas about science teaching and learning, and their attitudes towards science, and student gains because of these changes. Staff administering the programs observed changes in teachers' knowledge and attitudes. In addition, both teachers and staff have reflected on what components of the TTL model contribute to its success.

Science content knowledge: Both staff and participants expressed satisfaction with the "just-in-time" teaching model that emphasizes small-group instruction at times when participants are ready to learn. Nearly 100% of participants reported gains in science content knowledge.

The greatest area of gain was in hands-on, real world, local and regional examples and applications of basic science content resulting from connecting teachers to the wealth of local resources. Examples include field trips to local examples of geologic features, visits to industrial sites that use physical and chemical processes and working at the university laboratories or at their own schools with physics demonstrations, chemical laboratory materials and geologic samples. These experiences turned book learning they already had into more accurate and concrete understanding of both the science and its applications.

> I was overwhelmed at the amount of community resources available to us.
>
> My knowledge of the content…was out of a book and very limited…Now I have been immersed and experienced first-hand the geologic history of Wisconsin…I feel like a geologist…I thought before PESTO that geology was book work – not anymore. It can be hands-on, inquiry-based.
>
> My knowledge of science has changed dramatically. A completely new world has opened up for me.

TTL staff noted that although most teachers made gains in content understanding, the amount of progress varied widely among participants. Some teachers focused on relatively new content, while others focused on a very narrow but familiar topic and put their energy into classroom activity and materials development. In some teams, one teacher was already quite knowledgeable in the content areas pursued, and became the main content teacher for that group. In these cases, the rest of the group made the greatest gains in content knowledge.

Science pedagogy. Many teachers reported an increase in their understanding of science standards (national and state), and that they were challenged to consider alternative science teaching/assessment models through workshop activities. The changes teachers transferred into their own classrooms varied from individual to individual. Most included some component of inquiry-based learning. Examples of changes reported by teachers include: 1) eliciting student ideas, 2) requiring students to ask questions and make predictions, 3) requiring students to articulate their thinking and justify decisions, 4) adding student-driven investigations, 5) decreasing number of topics and increasing depth in some topics, 6) enriching content with local to regional examples, and 7) a change in assessment techniques to include measurement of process skills and real-world applications. One theme that is echoed in a number of teacher reports is that their TTL units were so successful that they were revising other units accordingly.

> My ideas of how students can learn have changed. Instead of starting with background info then inquiry – there are many places where starting with inquiry first would involve the students in the curriculum much more effectively.

Teacher attitudes. Teachers consistently reported a more positive attitude about and a higher comfort level with the specific unit they developed or modified during their TTL program. They were self-confident and felt well prepared to teach the unit with all materials, including assessment tools, in hand. They also mentioned that they were able to make better connections between their topic and other parts of the curriculum because of their thorough preparation to teach it, and some found that their interest in a topic extended into their own non-professional lives. Some teachers expressed a change in their attitude towards standards-based and inquiry-based teaching; they now felt these could be effective. In fact, in earlier TTL workshops, some teachers began to question their district curriculum, which had not yet instituted a standards-based curriculum.

> I now feel eager to teach soil and rocks. Children love rocks and now their teacher does, too.

> I had no idea Eau Claire, Wisconsin had so much valuable earth science information. I have found myself sharing information on land formations, Crystal Cave, fossils, American Materials, etc., with adult friends!

Impact on student learning. Documenting the scope and nature of impact of TTL projects on student learning remains a challenge. Yet, the available evidence suggests that many students are benefiting from teachers' improved knowledge, attitudes, and readiness to teach science through inquiry. In one workshop (TEES) we had teachers determine the number of students impacted in some way by their changed curriculum. This group of about 25 teachers reported 788 students affected during the course of the implementation phase in their own classes or classes of colleagues who got involved. This indicates the potential impact of this kind of program.

Teachers' reports about students' responses to TTL-designed units included evidence from students' oral and written work, such as a variety of student reports, journals, science logs, and idea webs, as well as student conversations, and in a couple of cases, student surveys. Teachers noted many examples of increased student enthusiasm and engagement in the science topic over previous years, and some noted that "difficult" students were motivated. They reported classroom discussions richer in science content and vocabulary, more complete and knowledgeable student written work, and greater student initiative including working on related activities during their spare time. Students asked more questions and initiated research related to the topic. In several cases, students became very attached to a topic and it became a recurring theme throughout the year. There were also examples of carry-over beyond the classroom, such as the article one student wrote on an exciting science activity for the student newspaper, discussions with parents and peers, and application of science concepts and skills at home and in the schoolyard. A number of teachers concluded that it was, in part, their own increased interest in the topic that helped generate student enthusiasm and motivation.

The current TTL model. The responses of middle and high school teachers in the PESTO projects mirrored those of elementary teachers who participated in early projects (e.g., CUBE and TEES). Teachers were very positive overall about their TTL experiences. Factors they cited as having the most impact for them were: 1) the time to focus on a curriculum development project of their own choosing, 2) the freedom to design their own project and their own work-plan, 3) the opportunity to talk with peers (other teachers and faculty) about teaching ideas, and 4) the individualized resources (money, facilities, people with expertise) available to help them achieve their goals. When asked to say specifically where they got the ideas used to plan changes in their instructional techniques, teachers noted three sources: 1) group activities and discussions conducted by staff that focused on teaching models and techniques, 2) individual discussions about pedagogy of specific units with PESTO staff, and 3) discussions with their peers about pedagogy. Content was learned primarily by individualized instruction from staff or consultants, and from resources (books, websites) provided by staff.

> "We were treated as professionals."
>
> The modeling by [the instructors] showed how important it is for students to be able to explore, question, analyze, etc. The process skills of science need to be utilized instead of focusing so heavily on just learning content.
>
> I found myself observing the instructors as they facilitated individuals and groups – they were kept extremely busy and seemed to be pulled in every direction by everyone's needs…. This model has shown me how valuable this type of work is to student learning, because I could sense so much enthusiasm as everyone shared his or her work at the end.
>
> "It is gratifying to see that what works with kids works with adults!"
>
> I took PESTO 2000 because of the money and the credits. I came back for PESTO 2001 because I found out it was a good program.

Why is the TTL Model Significant?

The TTL model has developed through the work of several different groups of people, including science teachers, science professors and education professors. Each group has a different set of issues that they believe to be significant about this mode of professional development. Below are statements from a participant teacher, from two scientist instructors, and from a science education instructor, that present different perspectives on the significance of the TTL model.

A Middle School Science Teacher's Perspective (by Dawn Olson)

My association with the PESTO project started with its first year, the summer of 2000. I have been a middle school teacher with the Eau Claire Area School District for the past seven years. I have attended many classes and workshops in my search for quality professional development. Some have been worth my time, but more have been disappointing in the professional growth I have achieved through them. PESTO offered a different model of delivery that I found professionally and personally rewarding.

One of the more significant differences PESTO provided was the freedom to identify the area(s) I needed and wanted to strengthen to improve my teaching. Most of the development opportunities I had experienced prior to PESTO were delivered with a preset agenda. Parts of their plan may have helped me, but much of the time was not focused on areas I wished to work on. PESTO not only allowed me this freedom of choice but also required it. Each participant developed plans for growth and put it in writing. We identified what we wished to accomplish and established links to existing curriculums. We designed what the final product would be, the process we would follow to get there, and the resources we would need to reach this goal. It was like creating a personalized "wish list" for professional development and receiving the power to achieve it. This was important not only to the teachers in the workshop but also to students in our classrooms. Teachers are in the "trenches" so to speak and are the most familiar with how students learn. With the freedom PESTO allowed participants, we could focus attention on projects tailored to our schools, our classrooms, and our students.

The UWEC staff facilitating PESTO also wanted to nurture a sense of community between the University and area teachers and the teachers themselves. The staff monitored the PESTO class and made their expertise readily available to the participants. After creating our own professional development plans, we were "matched" with the participating professor that best fit our needs. Participants had a one-on-one opportunity to work with professors in their area(s) of inquiry. Other workshops had certainly provided professional presenters, yet individualized time with these resources was not available. PESTO is different. For example, the participants identified fieldtrips that would add to their experience and the professors scheduled the trips, guided the trips, arranged transportation for the trips, and in many cases provided follow up information about the sites visited. These fieldtrips had a direct effect on student learning since they led to a number of participants going back to their schools and arranging for students to take part in similar fieldtrips to expand the learning experience.

Many of the participants in PESTO were also developing more "hands-on" or inquiry based activities (labs) to compliment the existing science curriculum in their classrooms. Again the professors provided science laboratory rooms, supplies, resources, and themselves to assist the teachers in doing this. This form of tailored inquiry allowed my fellow teachers and myself to truly work as scientists in the areas we had identified. Science teachers are "closet" scientists with few opportunities to practice our craft. PESTO gave us the opportunity to do so, expanding our knowledge base and our students' resources.

As a follow up many of the participating teachers have arranged for the PESTO staff to come into classrooms during the school year as guest speakers and presenters for students. In addition, college students working with the UWEC professors, hoping to be teachers themselves one day, have gained access to many more classrooms and teaching styles through the PESTO link. The potential of this connection to improve education for middle and high school students both now and in the future is priceless. Colleagues in the workshop networked with each other sharing ideas and activities. As one fellow participant said, "If I have questions or need ideas, I can contact any of these creative people."

Another area of support that PESTO offered to educators was financial assistance in the form of graduate credit for work done and stipends for attending the workshop. While this is not the first consideration of teachers looking for professional development opportunities, it is certainly a welcome one. Continuing education requirements are expensive and time consuming. Teachers who may not have opted to participate in a summer program may be motivated by the benefit of graduate credit earned at low or no cost. The organizers of PESTO also negotiated with participating school districts for small supply budgets to aid teachers in their project implementation. With shrinking school budgets, teachers are rarely allotted funds to use at their discretion. Unfortunately many great ideas are left unused for lack of funds. With these small supply budgets from our districts most of the projects developed through PESTO are in use in classrooms today broadening and strengthening our students educational experiences. I still use both the materials and the activities. Of course, I change things and add to them, but I build on what was started at PESTO.

Finally, I would like to address the issue of professionalism. Though teaching is considered a profession, we are not always treated as professionals. All too frequently decisions are made for us, agendas are set to meet needs we do not express, and monies are spent without our input. However, the PESTO model of professional development gave us control over our own learning. The participating teachers and their needs were the focus of the project. There were no preset agendas; our professional goals were our own to set and achieve. Organizers of the workshop offered their assistance but never forced it upon us. Boundless resources were provided to us in a variety of formats, including personal interaction with the PESTO staff. The communication between workshop providers and participants allowed the networking of educators to take place. An atmosphere of sharing and mutual respect set the tone for the entire workshop. In short, PESTO treated the participating teachers as professionals; it was a most rewarding and gratifying experience. "It seems like if someone has something "bad" to say about PESTO, it would be their own fault, since we were allowed to design our own staff development, which is something I really appreciated…"

Professional Scientists' Perspectives (by Bob Eierman and Erik Hendrickson)

The beauty of the TTL model is that the workshop structure is consistent with inquiry-based teaching methods. Teachers are asked to be the primary investigators and learn and develop their curriculum in a manner similar to the way students are asked to investigate and learn in the classroom. The workshop instructors serve as consultants and guides rather than as purveyors of knowledge. The teachers work to dig out new material and methods with the help of the instructors. Teachers are treated as colleagues and co-investigators with valued understanding and opinions just as students in inquiry-based classrooms are considered to be collaborators and investigators. Many teachers have made profound changes in their teaching because they recognize that they have learned very well in the inquiry-based environment of the workshop and feel that their students will learn well that way, too. As scientists, we are appreciative that this model is consistent with the scientific method and with science education standards.

Teachers need the opportunity to work to develop and adapt their curriculum, but they need resources and support to make that work be effective. The TTL model provides teachers with time as well as intellectual, logistical and monetary support. The teachers are given freedom, but are also given clear expectations regarding what they must do to satisfy the workshop requirements. They are treated as professionals and universally respond as professionals. Rich conversations about science teaching occur with teachers at a variety of grade levels providing their unique perspectives. These interactions produce a vibrant community of learners who openly share their knowledge of teaching/learning and science. The materials they develop are top quality and are needed for and utilized in their teaching. It is a pleasure to be able to coordinate an experience that enables teachers to improve their science teaching and enrich themselves as scientists.

We have also found that the TTL experience has had a positive effect on our own classroom teaching. The process of science and scientific inquiry has become more a part of our courses because of our work with these issues in the workshops. These have made our students' learning richer and fuller in terms of understanding how science works.

A Science Educator's Perspective

The TTL model is one example of an emergent community of learners where traditional boundaries and hierarchies are replaced by collaborative efforts to understand what it takes to improve classroom learning. Thus, titles such as "science educator" and "professional scientist" are more reflective of our daily job functions than real separations of roles in the community. Each time we complete a project, we end up with greater insights into the complexities of practice. We have come to function as partners, not always agreeing but always sharing the larger goal of making science interesting, accurate, and accessible.

University preservice teachers experience a more coherent set of learning experiences that include many more instances of learning science through inquiry and working with instructors who model the strategies they are expected to learn to use in their own teaching. As preservice teachers learn to design and use a range of approaches during their teacher education courses, they bring science learning experiences that are consistent with the messages sent through their education courses. The techniques modeled in methods courses are shaped by feedback from classroom teachers and in many cases are drawn from the examples presented by teachers in their TTL projects. In classrooms, preservice teachers are mentored by K-12 educators who value and use the same knowledge, skills, and dispositions. Thus, the collective impact on beginning teachers is far greater than could be achieved by any of the groups working alone.

A sense of trust and empowerment has emerged over the course of the projects. Teachers are trusted professionals invested in their own growth and who will make sound assessments of their own needs and act accordingly. University educators are trusted as knowledgeable yet not judgmental, and respectful of the teachers' professional wisdom. . It has become possible and acceptable to balance the insights from research and theory with the wisdom of practice. We can call each other and ask, "Is this a dumb idea?" or "how would you teach this?" and recognize that there will be more than one best answer. We know much more now about the dilemmas and politics of other's teaching situations that we did when the TTL projects began. It is rich knowledge.

Lessons Learned Along the Way

The TTL staff and participants have modified details of program planning based on previous successes and failures. Some of the current issues and our responses to them are listed below.

1) The model does not work for all teachers. Teachers must be self-motivated and have enough experience to have ideas about what component of their curriculum they want to develop. As we learned to screen potential participants we had fewer unsuccessful participants. We also learned to give only two credits for workshop completion and saved the third credit for completing the implementation and final reporting phase.
2) Defining a project of the right scope for the time available is difficult for some teachers. With experience, staff became better at guiding teachers in setting realistic goals.
3) Teachers need to be self-directed, but they also need checkpoints with staff to be sure they are making progress, and so that staff can effectively provide the resources needed.
4) There is a delicate balance between having too many and not enough group activities. One year we offered the group so many field trips, technology lessons and presentations on a variety of topics that some teachers had trouble focusing on and completing their own project. Another year both teachers and staff felt that collegiality did not develop throughout the group because we did not do enough activities together. So far our experience has been that the lower the grade level taught, the greater the collegial bonds are developed among teacher participants.
5) Formal interaction among participants during the classroom implementation phase in the form of peer observation was planned during an early TTL program. Although funds for substitutes were provided teachers did not take advantage of this opportunity. They felt the effort was not worth the potential gains.

6) It was difficult, given the budget, scope, and individuality of the TTL programs, to collect objective data on student gains resulting. We have had to rely on teacher reporting.

7) Securing funding for projects such as the TTL is challenging. Reviewers express concern that so much time is left unstructured and that the staff-participant ration seems excessive. Care must be taken in describing the roles of staff and illustrating how participants' progress is monitored to make a convincing case to funding agencies.

8) Follow-up sessions in particular need to be carefully designed to make expectations and incentives clear. We learned that participants would rather work independently in advance rather than meet together to complete revisions. It also became apparent that some accountability for completing the work needed to be built into the follow-up sessions (we used the third credit and partial reimbursement) to encourage thoughtful revisions and production of polished final products.

Closing Thoughts

The time-to-learn model is powerful. Through it, we are able to implement many of the characteristics of sound professional development highlighted in policy documents such as the National Science Education Standards, the literature describing sound professional development, and have done so in a manner that is responsive to teachers' voices about their own professional growth. A next step is to secure support for more extensive and direct documentation of the ways that TTL approaches impact student learning and teachers' thinking. We are also considering the ways that the community development accomplished in the current model might be extended to support other groups such as new faculty in Arts and Sciences departments, where there is often little or no real support for learning to teach well.

Clearly, the approach presented in this paper requires commitment beyond that of the participants. Institutional priorities must communicate a sense of value for collaborative effort. TTL approaches are time and resource intensive. Yet, the outcomes are diverse and reach many audiences. Replicating the approach used in the TTL projects, though, is less a matter of time and money than a matter of commitment to a way of thought. The time to learn model is a sound approach to improving the quality of science education at all levels.

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ASSESSING THE IMPACT OF UNDERGRADUATE MATHEMATICS AND SCIENCE INSTRUCTION ON BEGINNING TEACHERS' INSTRUCTIONAL PRACTICES

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Introduction

Nearly five years ago the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) was established, funded by the National Science Foundation. It was designed to improve the preparation of science and mathematics teachers in elementary, middle and high schools and attract a more diverse group of students to the teaching profession. As OCEPT approached its fifth and final year, a variety of evaluation strategies were developed in order to determine its effectiveness. The over-arching questions are:

1) Are we producing more and better mathematics/science and elementary teachers in Oregon?
2) Are we producing a more diverse teaching workforce?
3) What has OCEPT's impact been in the process?
4) What will OCEPT's legacy become?

In order to answer these questions, the following methods have been implemented:

1) Data have been collected over the previous four years to determine trends in the preparation of pre-service teachers as they enter teacher education programs;

2) A Faculty Fellows' Tracking Analysis annually documents Faculty Fellows self-evaluation and peer review regarding instruction, recruitment, institutional impact, dissemination, and course development.

3) A Peer Assessment Team has followed minority/underrepresented enrollment and retention through Excel-type courses, Faculty Fellow efforts in recruitment for teacher education, and Fellows' initiatives for incorporating standards-based teaching in their courses;

4) Institutional Case Studies are being written to document the narratives of faculty change and institutional change as a result of OCEPT impact;

5) An Outcomes Research Study documents the impact OCEPT Fellows and their courses have had on the quality of newly-licensed Oregon teachers.

This paper will focus primarily on the Outcomes Research Study and the instruments developed for its implementation.

The Outcomes Research Study

Problem Statement:

Mathematics and science courses tend to promote the success of those who major in the subject and find the subject matter intrinsically interesting thus limiting the number of students who enroll in mathematics/science courses. Elementary and middle level teachers teach mathematics/science to all students at a pivotal point in our educational system. They form an important population who should take mathematics/science courses and should enjoy a valuable experience.

Making mathematics/science courses more effective for a broader range of students is an important goal for making a mathematics/science literate society and especially in preparing future elementary and middle level teachers. Methods for more effective teaching and assessing that will motivate and challenge students who are not majoring in mathematics/science and may not find these content areas interesting, have a research base in the literature of mathematics and science education. These methods have also been highlighted in recent reform documents in mathematics and science education.

The OCEPT Response

OCEPT was designed to foster innovations in the teaching and assessment of college level mathematics and science courses. Prospective elementary, middle level and secondary teachers who take these courses will have firsthand experience in learning mathematics and science through the use of strategies and technologies that should benefit them as learners and support more effective pedagogy when they begin their own teaching. They should view these courses as a valuable component in their preparation for classroom teaching.

Research Study Questions

1. What is the relationship between student teachers' instructional practices and their undergraduate preparation?

2. Did Faculty Fellows' participation in OCEPT contribute to their instructional design and practice?

3. Do student teachers'/Faculty Fellows' teaching practices reflect those recommended by current research in math/science education?

4. What is the relationship between student teachers'/Faculty Fellows' perceptions of their own instruction and the observed classroom practice?

Pilot Study

At three institutions (OSU, University of Portland, Pacific University), students were identified who were currently accepted into a teacher education program, were working toward an elementary authorization, and had taken several courses from OCEPT Fellows. During the Pilot Study, interview and observation protocols were designed, field tested, and evaluated for validity by expert groups.

Outcomes Research Study Progress

The protocols are currently being implemented in an expanded number of institutions with at least twenty student teachers. Data will be collected through multiple sources, as identified below, for purposes of triangulation.

A. OCEPT Faculty Fellows:

Evaluating instruction in college courses:

- Interviews relatd to OCEPT goals, OCEPT-related activities, course modifications – using the O-TOP instrument
- Multiple observations of faculty teaching, using field notes and summarized in the O-TOP instrument

B. Identified/impacted student teachers in Teacher Education Programs:

Evaluating effects on new teacher instruction:

- Interviews to determine extent of impact of OCEPT course(s) including understanding of subject matter and standards-based teaching
- Multiple observations of student teaching experiences, using field notes and summarized in the O-TOP instrument

Resources

This paper is primarily focused on the development and utilization of the OCEPT-Teacher Observation Protocol (O-TOP) and the OCEPT-Teacher Interview Protocol (O-TIP). The development of these two instruments was largely informed by the following documents; see annotations.

Table 1

Resources for Development of Instruments

Author	**Description**
Dana, L. (Fall 2000). *The situated*	Describes eight dimensions of an observation protocol for

laboratory activity instrument (SLAI): A user's handbook. Unpublished paper.	assessing laboratory instruction. Two dimensions are student's role and teacher's role. Each dimension is scored on a scale from 0 to 3 with description of each scale value for each dimension. 'Nature of science has been' explicitly added to this protocol.
Lawrenz, F., Huffman, D., Appeldoorn, K. & Sun, T. (2001). *Classroom observation handbook.* University of Minnesota.	The NSF Collaboratives for Excellence in Teacher Preparation (CETP) projects commissioned a Core Evaluation program, directed by Frances Lawrenz, to provide data about the CETP programs as a whole using data from individual projects. The Core group developed a Higher Education Survey Handbook, a K-12 Survey Handbook, and the Classroom Observation Handbook.
Lederman, N. G. & Schwartz, R. (2001). *Nature of Science and scientific inquiry: Operational definitions and teaching approach as promoted in Project ICAN.* Unpublished paper.	Describes relevant characteristics of the nature of science and scientific inquiry appropriate for classroom teaching. Describes what students should know and be able to do. Teacher functions are anchored to the Herron (1971) scale and Table 2-5 of Inquiry and the National Education Standards (NRC, 2000).
Horizon Research Corporation, Inc. (1999) *Local systemic change core evaluation data collection manual.* Chapel Hill, NC: Author.	Provided the basis for much of the classroom observation protocol developed by the CETP CORE group.
NCTM Principles and Standards for School Mathematics. (2000). Reston, VA/Author.	A synthesis and synopsis of the earlier documents (NCTM "Curriculum and Evaluation Standards", "Professional Standards and Assessment Standards", "Assessment Standards"). With an emphasis on problem-solving and communication in mathematics, these documents describe appropriate pre-service preparation as well as ongoing professional development.
NRC National Science Education Standards – Teaching Standard B	A teacher should: - focus and support inquiries while interacting with students

(NRC, 1996, p. 32)	- orchestrate discourse among students about scientific ideas - challenge students to accept and share responsibility for their own learning - recognize and respond to student diversity and encourage all students to participate fully in science learning - encourage and model the skills of scientific inquiry as well as the curiosity, openness to new ideas and data, and skepticism that characterizes science.
Roseman, J. E., Kesidou, S., & Stern, L. (1995). *Analyzing curriculum for science literacy.* Online: www.project2061.org/newsinfo/research/roseman/roseman2.html.	This curriculum tool contains seven categories (Clusters) for assessing science curricula. Elements of each cluster have instructional implications.
Sawada, D. & Piburn, M. (March 2000). *Reformed teaching observation protocol (RTOP): Training Guide.* Arizona Board of Regents.	Provides description and rationale for observational categories for assessing classroom instruction. Characterizes any classroom on a quantitative scale of reform. These categories include (a) Contextual background, (b) Lesson design and implementation, (c) Content, and (d) Classroom culture.
Social Science Education Consortium (Fall 1994). *Teaching about the history and nature of science and technology: Teacher's resource guide. Field test edition.* Colorado Springs, CO: Author.	Uses the 5E model and provides teacher and student actions consistent with the model. Also provides actions that are inconsistent with the model. The 5E model is outlined and referenced to BSCS, 1985.

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OCEPT-Teacher Observation Protocol (O-TOP)
Outcomes Research Study – 2001

This instrument is to be completed following observation of classroom instruction. Prior to instruction, the observer will review planning for the lesson with the instructor. During the lesson, the observer will write an anecdotal narrative describing the lesson and then complete this instrument. Each of the ten items should be rated 'globally'; the descriptors are **possible indicators**, not a required 'check-off' list.

	Not Observed				Characterizes Lesson
1. **This lesson encouraged students to seek and value various modes of investigation or problem solving.** (Focus: Habits of Mind)	N/O	1	2	3	4

Teacher/Instructor:
- Presented open-ended questions
- Encouraged discussion of alternative explanations
- Presented inquiry opportunities for students
- Provided alternative learning strategies

Students:
- Discussed problem-solving strategies
- Posed questions and relevant means for investigating
- Shared ideas about investigations

2. **Teacher encouraged students to be reflective about their learning.** (Focus: Metacognition – students' thinking about their own thinking)	N/O	1	2	3	4

Teacher/Instructor:
- Encouraged students to explain their understanding of concepts
- Encouraged students to explain in own words both what and how they learned
- Routinely asked for student input and questions

Students:
- Discussed what they understood from the class and how they learned it
- Identified anything unclear to them
- Reflected on and evaluated their own progress toward understanding

3. **Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students.** (Focus: Student discourse and collaboration)	N/O	1	2	3	4

Teacher/Instructor:
- Organized students for group work
- Interacted with small groups
- Provided clear outcomes for group

Students:
- Worked collaboratively or cooperatively to accomplish work relevant to task
- Exchanged ideas related to lesson with peers and teacher

4. **Intellectual rigor, constructive criticism, and the challenging of ideas were valued.** (Focus: Rigorously challenged ideas)	N/O	1	2	3	4

Teacher/Instructor:
- Encouraged input and challenged students' ideas
- Was non-judgmental of student opinions
- Solicited alternative explanations

Students:
- Provided evidence-based arguments
- Listened critically to others' explanations
- Discussed/Challenged others' explanations

5. The instructional strategies and activities probed students' existing knowledge and preconceptions.
(Focus: Student preconceptions and misconceptions)

N/O 1 2 3 4

Teacher/Instructor:
Preassessed students for their thinking
Helped students confront and/or build on their ideas
Refocused lesson based on student ideas to meet needs
Students:
Expressed ideas even when incorrect or different from the ideas of other students
Responded to the ideas of other students

6. The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.
(Focus: Conceptual thinking)

N/O 1 2 3 4

Teacher/Instructor:
Asked higher level questions
Encouraged students to extend concepts and skills
Related integral ideas to broader concepts
Students:
Asked higher level questions
Related subordinate ideas to broader concept

7. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.
(Focus: Divergent thinking)

N/O 1 2 3 4

Teacher/Instructor:
Accepted multiple responses to problem-solving situation
Provided example evidence for student interpretation
Encouraged students to challenge the text as well as each other
Students:
Generated conjectures and alternate interpretations
Critiqued alternate solution strategies of teacher and peers

8. Appropriate connections were made between content and other curricular areas. (Focus: Interdisciplinary connections)

N/O 1 2 3 4

Teacher/Instructor:
Integrated content with other curricular areas
Applied content to real-world situations
Students:
Made connections with other content areas
Made connections between content and personal life

9. The teacher/instructor had a solid grasp of the subject matter content and how to teach it.
(Focus: Pedagogical content knowledge)

N/O 1 2 3 4

Teacher/Instructor:
Information presented was accurate and appropriate to student cognitive level
Selected strategies that made content understandable to students
Was able to field student questions in a way that encouraged more questions
Recognized students' ideas even when vaguely articulated
Students:
Responded to instruction with ideas relevant to target content
Appeared to be engaged with lesson content

10. The teacher/instructor used a variety of means to represent concepts. (Focus: Multiple representations of concepts)

N/O 1 2 3 4

Teacher/Instructor:
Used multiple methods, strategies and teaching styles to explain a concept
Used various materials to foster student understanding (models, drawings, graphs, concrete materials, manipulatives, etc.)

Outcomes Study
OCEPT Teacher Interview Protocol (O-TIP)

Student thinking
How does your instruction support development of thinking skills?

1. [Habits of Mind] This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.

2. [Metacognition] Teacher encouraged students to be reflective about their learning

5. [Students preconceptions and misconceptions] The instructional strategies and activities probed students' existing knowledge and preconceptions.

7. [Divergent Thinking] Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.

Social skills & collaboration
How does your instruction support development of social and collaborative skills?

3. [Students discourse and collaboration] Interactions reflected collaborative working relationships among students (e.g., students worked together, talked with each other about the lesson) and between teacher/instructor and students.

Content
How does your instruction support development of content understanding?

4. [Rigorously challenged ideas] Intellectual rigor, constructive criticism, and the challenging of ideas were valued.

6. [Conceptual thinking] The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.

8. [Interdisciplinary connections] Appropriate connections were made to other areas of mathematics/science, to other disciplines, and/or to real-world contexts, social issues, and global concerns.

9. [Pedagogical Content Knowledge] The teacher/instructor had a solid grasp of the subject matter content and how to teach it.

Instruction
Besides student thinking skills, content understanding, and social/collaborative skills, what else guides your selection of instructional approaches?

10. [Multiple representations of concepts] The teacher/instructor used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.

Student teachers: In your undergraduate classes, what strategies were modeled that you now use? How did your undergraduate preparation contribute to your instructional design and practice?

Faculty Fellows: Describe your level of participation in OCEPT activities. How has your affiliation with OCEPT contributed to your instructional design and practice?

L. Flick, P. Morrell, C. Wainwright – 10/15/01 http://www.mth.pdx.edu/OCEPT/

HELPING MIDDLE SCHOOL SCIENCE STUDENTS RELATE TO NEW CONCEPTS THROUGH PHYSICAL MODELING: A BODILY-KINESTHETIC APPROACH

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Problem Statement

Much of traditional science instruction is directed toward logical and verbal intelligences, through assigned textbook readings and teacher-given lectures. However, not all students have their predominant strength in these areas. Gardner has now described nine different types of intelligence, including verbal/linguistic, logical/mathematical, spatial/visual, musical, interpersonal, intrapersonal, bodily-kinesthetic, naturalist, and existential (Campbell & Campbell, 1999) in which people have varying degrees of strength. For some science students, it can be difficult to grasp a concept by merely reading about it from a text book. Even adding material from lectures may not give them an adequate understanding. Many of the middle school level science concepts are quite complex and cannot truly be seen or directly observed. To compound the difficulty, not all learners have strength in visual or spatial intelligence and so have greater difficulty visualizing a concept without the presentation of a model. All of these challenges can lead our students to perceive science topics as very foreign. This can lead to discomfort with science.

My teaching goals in the science classroom include increasing motivation, involving students in their own learning, and for each student to better comprehend the subject matter. As a science educator, one of my tasks is to provide a learning environment that is comfortable for each student so they will feel confident in their ability to learn. I believe that incorporating a variety of instructional methods into my teaching repertoire will help me to accomplish this task. This notion is supported by research that describes people as capable of comprehending material through a variety of learning mechanisms (Sternberg, 1995). Jones & Jones (1998) said that "students learn best ... in classroom settings that meet their learning needs" and "students vary in the type of classroom structure and instruction that best facilitate their learning" (p. 178). I have used physical modeling, or simulations, of science concepts as part of my instructional repertoire in order to decrease students' anxiety, to help students to feel involved in their education, and facilitate understanding of the material through an increase in comfort with the topics of study.

Purpose

In this action research project I evaluated my implementation of physical modeling in the science classroom and determined its success as a teaching strategy. In this case, "success" is defined by my ability to implement lessons of this nature. I also evaluated the effect of this method on student comfort with learning about science. Goals of using this teaching method include increased student motivation to learn, and increased comprehension of, and comfort with, complex and abstract science topics. Future studies will analyze the effects of this instructional technique on comprehension and motivation among my students.

Background/Theory

The Theory of Multiple Intelligences, as developed by Gardner of the Harvard Graduate School of Education, claims that all humans "have the potential to develop a set of relatively autonomous intellectual faculties, called the multiple intelligences" (Sternberg, 1995, p. 740). Research performed in the area of learning style preference has determined that individuals do have specific preferences, that these can be identified, and suggests that "academic achievement is enhanced when student learning style is considered in the selection of instructional methods" (Dwyer, 1998, p. 137-138). Additional research has noted that "most people prefer learning by experiencing and doing, especially when reinforced through touching and movement" (Brown, 1988, p. 3).

It is common knowledge that females tend to become less comfortable with mathematics and science courses as they progress through their school years. Science instruction also tends to become increasingly focused on instruction from the textbook as students progress through the grades. Owens and Cooney (1998) suggest that addressing multiple intelligences and learning styles in the classroom help to overcome gender bias and encourage girls to excel in their studies. They specifically suggest providing "hands-on opportunities on a weekly basis in order to increase participation by girls" (p. 29). Brown (1988) reports that instruction rooted in the student's preferred learning style reduces anxiety and that women in the study who demonstrated higher levels of anxiety preferred analytical and hands-on types of instruction and learning. Findings cited by Brown indicate that female students benefit most from instruction geared toward hands-on learning in practical settings.

Research involving hands-on learning in a mathematics course concluded that students preferred this type of instruction and that their attitudes toward the subject improved as a result of its use. In addition, it was found that the use of manipulation of physical objects improves motivation and "leads to scientific types of problem solving behaviors" (Garrity, 1998, p. 21).

Students have certain basic academic needs, among them are that students "be actively involved in the learning process and relate subject matter to their own lives", "have positive contact with peers" and "receive instruction matched to their learning style" (Jones & Jones, 1998, p. 182). Simulations, as explained by Orlich, Harder, Callahan, Kravas, Kauchak, Pendergrass, and Keogh (1985), are used to "reduce complex problems or situations to manageable elements" (p. 307) and "increase student interest in the subjects being studied" (p.

320). Their use can motivate learners, develop analytical processes, and assist students in realizing that knowledge gained in one area may be applicable elsewhere.

Since many people prefer learning through kinesthetic instruction (Brown, 1988), I believed physical modeling of science concepts would aid a majority of students in comprehending lesson material. Gardner (1995) stated simply, “When a topic has been approached from a number of perspectives...more children will be reached” (p. 208).

Research Question

This research project strove to answer two questions.

1. How can I incorporate physical modeling into my instructional technique?
2. Will the use of physical modeling improve student comfort with learning complex science topics?

Procedures

This section consists of five parts including descriptions of intervention, data collection, data analysis, the relationship between chosen procedures and the purpose of the study, and procedural support from professional literature.

Intervention

I have designed and implemented several lessons that incorporate body movement into explorations and explanations of science topics. Data was gathered to help me determine the benefits and difficulties of using physical modeling instruction and whether or not this led my students to have an increased comfort level with the information. This action research occurred at an urban, southeastern Washington middle school in one eighth grade science class. The general school population is predominately middle-class Anglo-American. My focus group consisted of one male and three female students selected by my mentor teacher to provide one student of high initial comfort, two with medium initial comfort, and one with low initial comfort with science. Comfort level was determined by indication provided through the attitude survey. A score of 9 or above with a maximum of 11 possible points indicated high initial comfort with science. A score of six to eight relates to medium comfort, while a score below six indicates low initial comfort with science. The focus group members were part of a class of 31 students. The eighth grade level was selected for this study since, during this year in science, the students begin to deal with physical and chemical science topics. Unlike the life science class of the previous educational year, many of the topics may be impossible to actually see and difficult to visualize. Lessons were designed to meet the Washington State Essential Academic Learning Requirements and district curriculum guidelines. Students were active participants in the modeling processes. All students received this same instruction, regardless of their status as focus group members or at-large class members. One additional consideration I addressed was the need to ensure the lessons were accessible to all of my students, regardless of physical movement abilities. The only challenges in that area were a broken arm and a broken leg. Neither case necessitated modification to lessons as there was no strenuous or fine motor movement required. The use of physical modeling was used in addition to traditional methods such as lecture, reading from texts, student note-taking, and completing worksheets and book problems. I incorporated eight lessons involving physical modeling instruction over the eight-week instructional period. Specific lesson areas were identified after meeting with my mentor teacher. They included lessons in chemical bond types (single/double), electron configuration, atomic stability, chemical bond for stability (electron shells), periodic table design, chemical reaction rates, isomers, and allotropes. The lesson plans are provided in Table 1.

Table 1

Lesson Plans Physically Modeled

Topic	Description
Chemical Reaction Rates	Many students are arranged in a cube-shape and act as molecules in a solid substance. Other students act as molecules of a liquid. The 'liquid molecules' walk over to the 'solid molecules' and pair up as in a reaction while noting the time required to complete the pairing. The parameters are changed so that the solid has been crushed and spread out (students stand in two straight lines) and the process is repeated - note the faster reaction time. Students are asked what would happen if the mixture was stirred. Model their response by having the molecules move around and note how they meet up more quickly. Repeat for scenario of adding heat by having students move more quickly.
Periodic Table Design	Students compare writing utensils and categorize themselves based on these comparisons. They seat themselves in chairs set in a circle to show their organization scheme based on the different physical characteristics of their writing utensil. The instructor then observes the arrangement and attempts to verbalize their classification scheme and place another utensil appropriately within the group. Other classification methods are suggested by teacher and students. Introduction to periodic table and its organization scheme follows with description of ways that it could be arranged and its currently accepted arrangement.
Electron Configuration	Large group interaction where each person is an electron; pairs of electrons are seated around a "nucleus" in the successive electron orbital shells to illustrate the number of electrons each shell can hold.

(table continues)

Table 1 (continued)

Topic	Description
Atomic Stability	Students act as electrons to represent an element on the periodic chart. Student 'electrons' are seated in the proper orbital shells, distributed one at a time within each orbital and then paired until the orbital is filled. As the energy levels are filled, student 'electron pairs' sit back-to-back. Students will see that single electrons are unstable - if they lean back, they will fall over. Students can also see that having an even number of electrons doesn't ensure atomic stability.
Chemical Bonding A	Large group interaction where each person is an electron; students are seated back-to-back in pairs around a "nucleus" using the proper number of electrons in one atom of a given unstable element (chlorine). The electrons are placed in the proper orbital shells. This is repeated for another unstable element (sodium). The students are directed to the 'unpaired' electrons in each atom and incompletely filled shells leading to lack of stability. The two 'spare' electrons bond to make a stable compound (NaCl - table salt).
Chemical Bonding B	Students experience flexibility and strength differences among single and double bonds by pairing with a partner and holding one hand together from each student (single bond) and comparing to holding both hands together (double bond). Can be done at or near individual seats.

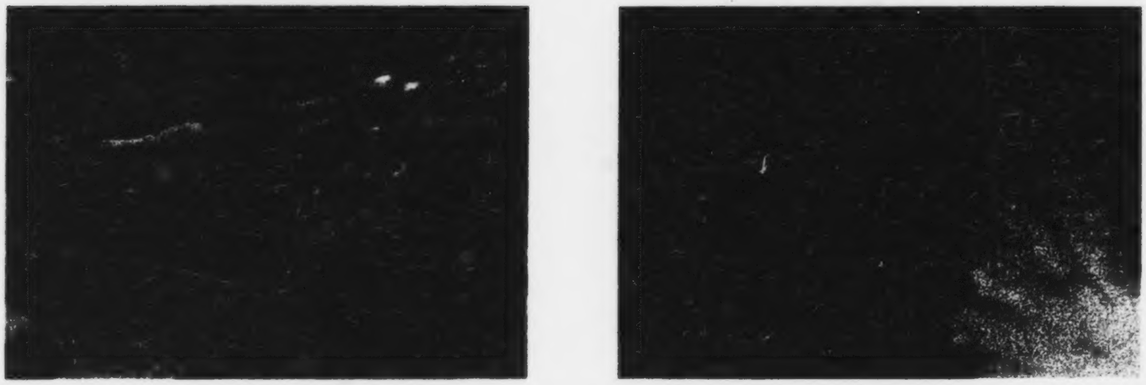
(table continues)

Table 1 (continued)

Topic	Description
Allotropes	Hold their hands flat with palms together and rub them back and forth to illustrate graphite and its lubricant characteristic. Then students make fists and gently rub knuckles together to illustrate diamonds, which are not good lubricants. Both are made of the same thing (hands represent carbon) but have different configuration and therefore different characteristics. Can be done at desks.
Isomers	Individual students represent carbon and hydrogen atoms in a butane molecule. Start with carbons in a straight line with their associated hydrogen atoms. Class members move around the carbon atoms (and their hydrogen atoms) to illustrate different possible isomeric configurations for butane. Structures are recorded on the board. Discuss why some configurations qualify as isomers and others do not.

An example of physical modeling for a chemistry topic is given in Figure 1. Students rub their hands together, palms facing inward, modeling the structure and lubricating property of graphite. Students then close their hands to make fists and gently rub the knuckled portions together to mimic the more complex structure and non-lubricating property of diamonds. Both materials are made of carbon. The materials (carbon/hands) remain the same, only the structure is altered. They are allotropes.

Graphite/Hand Diamond/Hand



Graphite chemical structure Diamond chemical structure

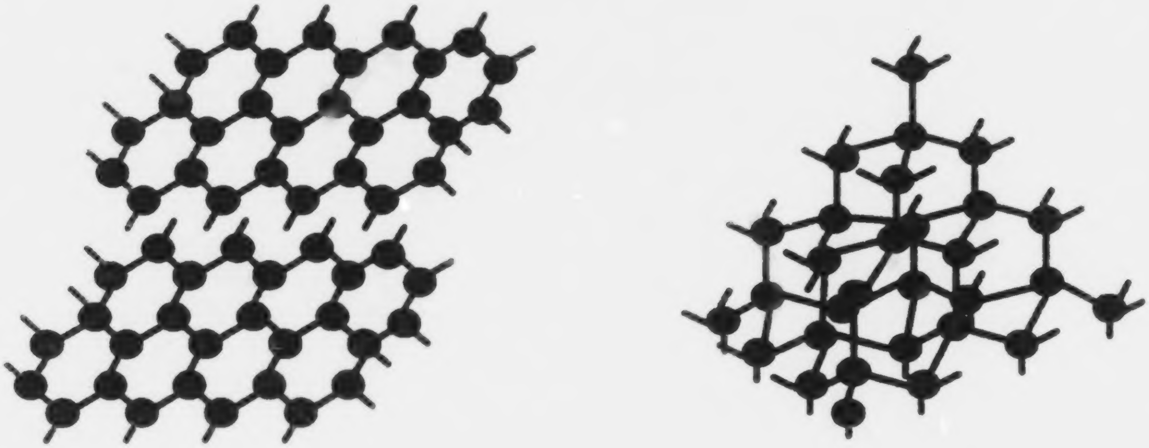


Figure 1. Example of physical modeling for physical chemistry topic "allotropes".

Seven additional lessons (described in Table 2) incorporated the relationship of subject matter to the physical self without students participating in a bodily-kinesthetic activity, though most could be performed in the classroom. These lessons dealt with the following topics: the number of electrons each orbital and energy level can hold, orbital energy level comparisons (s,

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p, d, f), the order of filling, electrons involved in bonding and relative position to the nucleus, electrons in atomic structure, ionic bonds, and molecules with both polar and non-polar regions.

Table 2

Lesson Plans Related to Physical Being (not modeled)

Topic	Description
Orbital Electron Capacity	Each orbital holds increasing numbers of electrons in increasing energy levels. Relate this to the number of people that different rooms in a house can hold. Broom closet = 's-level' (2 electrons); bathroom = 'p-level' (6 electrons); bedroom = 'd-level' (10 electrons); living room = 'f-level' (14 electrons).
Electron Energy Levels	'S-level' is lower energy level than the 'p-level' so it takes less energy to hold an electron in place in the 's-level' (it's closest to the nucleus) than in the 'p-level' (farther from the nucleus). It takes less energy to stand (close to the ground) than hold yourself over a chin-up bar (farther from the ground) so you are more likely to stay standing longer than you are likely to stay a long time over the chin-up bar.
Electrons in Atom Structure	Related to a multi-level building with flights of stairs - each stair step represents an electron, a flight of stairs is an energy level, a whole floor worth of stairs is an orbital, and all of the stairs in the building represent all of the electrons in the atom (the electron cloud).
Energy Level Filling Order	When going up stairs it is easiest to go one stair at a time, it takes less energy this way. Electrons are placed in successively higher energy levels after each lower level has been filled. There are exceptions but they take more energy, like when you skip a step when going up stairs.

(table continues)

Table 2 (continued)

Topic	Description
Electron Position/Bonding	Liken the 1st, 2nd, 3rd, and 4th orbital shells to a king and queen, the knights at the gate of the castle, an organized perimeter patrol, and the peasants who all act to protect the king and queen. The two electrons in the center are held there very strongly and are less likely to be involved in a reaction than the electrons farthest from the nucleus, like the king and queen on inside and peasants far from the castle.
Ionic Bonds	Tug-of-war demonstrates how one atom is stronger and can take electrons from another atom. Have seven 'people electrons' stand at one end of rope to represent chloride and one 'person electron' stand at the other end to represent sodium. Have a tug-of-war contest to see which atom takes and which is the donor. Use to introduce concepts losing electrons = oxidation and gaining electrons = reduction.
Polar & Non-Polar Regions	Form a football-style huddle to demonstrate the position of non-polar regions of a molecule vs. polar regions when in a polar substance, such as water, for protection of the non-polar regions. The heads of the players are inside the huddle to protect the sound of play instructions so no one else will hear. The non-polar regions of a molecule are on the inside to protect them from polar material. Discuss hydrophobic and hydrophilic.

Data Collection

An initial survey regarding students' attitudes toward science was administered to the entire class prior to the start of instruction (see Appendix A). The questionnaire used in this study is a modification of Garrity's work (1998, p. 35). The modification was replacing references to math with references to science. Students were purposefully selected for further observation based on the results of the initial survey. My mentor teacher made the focus group student selection at my request, based upon previously detailed criteria, so that I would not unknowingly exert an influence on the selection and choose students that I felt would benefit most from the physical modeling instruction. The research focus group originally consisted of a selection of five students. The group included one student who indicated high comfort level and many positive prior experiences with science, two students in a mid-range, and two students at the opposite end of the spectrum, indicating a low comfort level with science and few, if any, positive prior experiences. One of the students from the "low comfort" criteria was not used as part of the focus group due to repeated absences from class. This left a group of four students for focus, three females and one male. The purpose of having the focus group was to allow in-depth interviewing and observation of a small group with a range of comfort levels. This helped me to determine if my interventions would benefit students of low comfort level while not damaging the comfort of students with a medium to high initial level.

Following selection, an interview was performed with each student in the focus group. Interview questions were based upon the written questionnaire and were used to delve deeper into the students' positions on the subject (see Appendix B). Information gathered through the interview process was correlated with data from the written questionnaires. Two surveys were used to reveal individual multiple intelligence strengths and learning styles of the focus group. The first part (Activity 1: How I use my physical senses to study or work) from "Style analysis survey: Assessing your own learning and working styles" by Oxford (1998, p. 179-183) was administered to each focus group member and showed students' preferences for visual, auditory, or hands-on learning. An inventory of multiple intelligences was generated through administration of a survey adapted from "Student-generated inventory for secondary level and young adult learners" by Christison (1998, p. 160-161) (see Appendix C). The multiple intelligences survey was also administered to the entire class. I scored the multiple intelligences surveys and reported the data to each class member individually. An explanation of the intelligence areas, along with study hints, was given to the class as a whole. Classroom observations of the sample group were documented in a self-reflective journal as were informal discussions with students throughout the course of the research. The discussions centered on the students' comfort with presented topics and their analysis of my specific lessons. Following eight weeks of instructional time incorporating physical modeling, the attitude surveys were repeated for comparison with initial data. A second, post-instruction interview was performed with each member of the focus group. These questions are included as Appendix D. The use of multiple data sources assures the validity of the data gathered. Data was collected according to the timeline given in Table 3.

Table 3

Data Collection Timeline

Week	Data Collection Type
1	Observations, attitude survey, multiple intelligences survey
2	Review multiple intelligences survey data with whole class and individuals
3	Focus group selection
4	Pre-instruction interviews
4-12	Instruction, reflective journal, informal student conversations, videotape
13	Post-instruction attitude survey, post-instruction interviews, mentor teacher reflections

Data Sources

1. Attitude survey-- administered at beginning and end of research period
2. Interviews to expand on attitude survey and physical modeling learning experiences (audio taped and transcribed)-- administered at beginning and end of research period
3. Learning styles and multiple intelligences surveys
4. Teacher reflection in journal format (including observations and informal discussions with students)
5. Videotape of lesson that incorporates physical modeling
6. Mentor teacher reflections (audio taped and transcribed)

Data Analysis

All surveys and questionnaires were evaluated prior to use to ensure validity of data. Surveys used include a previously published document (learning styles) and modifications of previously published documents (attitude and multiple intelligences surveys). These were evaluated by my expert group for appropriateness of use. This expert group included my project advisory committee (faculty at WSU) and my field specialist. Fellow graduate students took the surveys as a pilot test as a check for functionality errors.

My mentor teacher, utilizing the results of the attitude survey, selected the focus group. Administration of the learning styles survey followed the selection of focus group members to prevent undue influence of this knowledge on the selection of the group that was observed. Results of the multiple intelligence and learning style surveys were compared to the pre-instruction attitude survey. The purpose of determining multiple intelligence and learning style preferences was to correlate comfort with these preferences and to provide an opportunity to look for counter-examples to the success of the physical modeling instructional technique. Specifically, I needed to know if the use of a bodily/kinesthetic, hands-on approach such as physical modeling is detrimental to the learning comfort of students who do not prefer this learning environment. To do so, I needed to know the preferred learning styles and intelligences of the students. Science instruction often involves a great deal of traditional instruction such as lecture and "book learning." I wanted to know if those students who express discomfort with learning in the science classroom are of a preferred learning style other than auditory and visual, and of preferred multiple intelligences other than logical/mathematical, verbal/linguistic, and spatial/visual. Through incorporating classroom experiences involving bodily/kinesthetic, hands-on learning, I attempted to provide those students with the opportunity to be comfortable with science learning. Multiple intelligences surveys were evaluated and tabulated for each class.

Pre-instruction and post-instruction attitude surveys administered to the focus group were compared and evaluated for changes in attitudes toward science topics. Pre- and post-instruction interviews were transcribed and interpreted for correlation with attitude surveys, multiple intelligences data, and learning styles preferences. The attitude survey and multiple intelligences scoring spreadsheets were shared with a fellow teacher-researcher and discussed to ensure the results were being properly tabulated.

The reflective journal kept by myself, the teacher-researcher, was coded for trends and evidence of the benefits and challenges associated with incorporating physical modeling into my instruction as well as for the effects of this type of instruction on student attitude and comfort level with science learning. This journal included direct observations, notes from viewing the videotape, and reflections on mentor feedback.

Results from the different forms of data collection have been compared to examine consistency. All data was examined for evidence of examples counter to the hypothesis that the incorporation of physical modeling into my instructional technique is both possible and beneficial to improving students' comfort with science learning.

Results

The following section describes the various results obtained from each data source.

Attitude Survey

A comparison of pre- and post-instruction attitude surveys revealed several results. There were no substantial decreases in overall scores between pre- and post-instruction surveys. This shows that general comfort levels did not decrease among students initially indicating low, moderate, and high levels of comfort. One student expressed a decrease in enjoyment of the homework but attributed that to the subject matter rather than instructional technique. Two of the four focus group members had no substantial change in their attitude surveys. The low initial comfort focus group member changed from initially thinking the class would be hard to no longer thinking so. One of the two students whose initial survey showed a moderate level of comfort had a post-instruction survey showing a high level of comfort. Positive changes to this student's survey included now liking science, thinking that it is no longer often hard to understand, feeling science is now useful, and finding homework to be more interesting than before.

Interviews

The interviews given at the beginning, throughout, and after the instructional period of this research had many results. When discussing benefits of the lessons, students tended to comment on the interpersonal, visual, and hands-on nature of the physical modeling activities. Students tended to recall both the physical models and the scientific information presented. Drawbacks mentioned during interviews focused primarily on the organization of the lesson, such as the time necessary to move furniture and the need for colored jerseys to visually clarify which students represent different model parts. A secondary drawback focus was a concern that some teachers may try to teach using only this one technique. Three of the four focus group students expressed concern that some people wouldn't learn the material if it was ever presented in only this one way. This demonstrated awareness among those students of the variety of ways in which people learn. Additionally, those students with moderate to high initial comfort in science tended to be more aware of their own learning styles.

Multiple Intelligences Surveys

More than one-third of the 140 students in my five classes had a low comfort in the logical/mathematical intelligence area that is a traditional area for science instruction. Only seventeen percent showed a high comfort in this intelligence area. In the bodily-kinesthetic intelligence area, thirty-four percent of students revealed high comfort level with only sixteen percent having low comfort. This is nearly the inverse of the logical/mathematical intelligence results. The surveys also revealed a majority of students had great abilities in the interpersonal intelligence. The relative percentages of high, medium, and low strength in each intelligence area is presented in Figure 2.

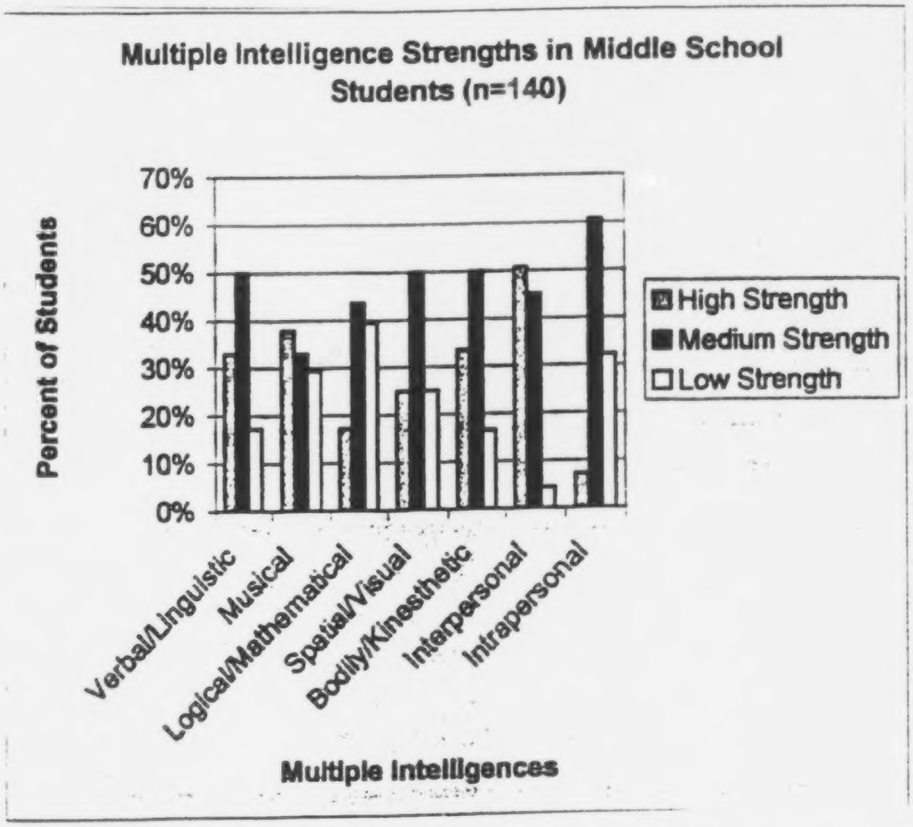

Figure 2. Chart of multiple intelligence strengths in middle school students.

Learning Styles Surveys

Assessment of learning styles demonstrated a variety of preferences. Some students showed a balance between visual, hands-on, and auditory while others showed a marked preference for only one or two of these.

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Journal

Coding and analysis of the journal kept throughout the course of my research revealed several results. There were some students who were not comfortable participating in physical modeling activities that involved physical contact with other students. On the whole, participation increased over time and with additional physical modeling experience. When given the opportunity to teach information to the entire class, some students felt comfortable enough with the physical modeling instruction to self-select this instructional technique and incorporated it into their presentation.

While classroom management was initially a challenging issue, such difficulties decreased with additional physical modeling experiences. The efficiency of instruction was greatly influenced by workspace arrangement. When the classroom furniture was arranged to facilitate physical modeling, more time was spent on instruction and less was spent on moving furniture and explaining to students where they needed to be.

Lessons incorporating physical modeling occurred an average of once per week. While there was an average of nearly two lessons per week that could have been modeled in the classroom, some were only discussed as topics that relate to the body and were not actually modeled. The physical modeling lessons I taught tended to involve the entire class and in a manner where they were interacting with each other. The lessons I did not have students actually model tended to be of the type that could have been accomplished individually.

Videotape

An assessment of the videotape showed three results. In regard to classroom management difficulties, not all students were on task and I was unable to visually monitor the majority of students at once due to the room layout during initial physical modeling activities. On a more positive note, most students were willing participants. During the videotaping, two members of the focus group verbally demonstrated clear understanding of the physical model and applied that understanding to problem solving.

Mentor Feedback

Discussions with my mentor teacher helped me realize that he had faced the same challenges with finding space as well as getting students involved and keeping them focused during physical modeling activities. These difficulties appear to be typical when incorporating this type of instruction. We each managed to overcome the difficulties and noticed clear benefits from the effort.

Relationship to Purpose

I believe the best source of information about attitudes and comfort level with material is the individual of concern. By asking the students directly, through surveys, interviews, and conversations if they are comfortable with and like science, I obtained the most accurate data available for each individual student. The reflections in my journal, including thoughts on conversations with students and observations about student interaction with topics studied in the class, enabled me to find trends in physical modeling implementation and student attitudes. Correlation of this information with that from more formal data collection processes, such as interviews, videotape, and surveys, allowed me to reach several conclusions.

Procedural Relationship to Professional Literature

The multiple intelligences survey, "Student-generated inventory for secondary level and young adult learners," by Mary Ann Christison and the learning style survey, "Style analysis survey: Assessing your own learning and working styles," by Rebecca Oxford are both from Joy M. Reid's book "Understanding learning styles in the second language classroom." How we each learn is important for all subjects and circumstances. The student attitudes survey was adapted from one presented in a paper detailing research in a mathematics classroom. The attitudes questioned apply equally well to science.

Conclusions

In reflecting on the first question in my research, "how can I incorporate physical modeling into my instructional technique?" I have come across three key issues. The first two directly involve the students.

There is some inherent difficulty with including physical activity in the classroom as, with the exception of physical education, the students are not accustomed such activity in middle school classes. They spend six periods a day enduring the traditional student role where they are seated at a desk and either reading or writing while the teacher lectures. Merely being out of their seats for a physical activity can disrupt classroom management as unfamiliarity with this type of instruction can lead some students to have difficulty focusing on the given task. Student involvement was also an issue I faced. While many students in my class are very sociable and outgoing, some are not comfortable working in a group environment, especially one in which they are being observed by their peers. Some of the lessons involved physical contact, such as holding hands to illustrate single and double bonds. Some students expressed discomfort with the aspect of physical contact with fellow students.

The second main issue is one of space. There is a natural lack of open space in the typical classroom. Most classrooms are filled with tables or have individual desks. There are also a large number of supplies requiring space.

My initial activities involved the entire class, required a large amount of open space, and necessitated student contact. Though most students were readily engaged in the activity, three of four members in the focus group were among the first to participate, a few needed much coaxing. The fourth member of the focus group was the last to participate. To obtain space I had to move all desks to the perimeter of the room and place the chairs in a circle near the perimeter. This removed student ability to access their note taking supplies, a disservice to those who need to write notes. Moving furniture also took a good deal of time away from instruction.

Though these issues are all contrary to supporting this type of instruction there are ways to overcome or minimize their impact and I believe the benefits outweigh the drawbacks. The following solutions were found to overcome the above-mentioned obstacles.

The student involvement issues were resolved to a certain extent through informal teacher-student discussions reflecting on specific lessons as well as through increased use of physical modeling as a routine part of instruction. The student in the focus group who was the last to participate in the first activity revealed that it was simply because he did not want to sit on the dusty floor. By respecting the needs of my students, and having two student-volunteers sweep the floor prior to this type of activity, I can help students to be more comfortable. An environment of trust needed to be built where all students were encouraged to participate and were confident they'd receive peer support during participation. Trust has increased in my classroom, though this environment is still evolving and there are some who may never be comfortable engaging in this type of "public" activity. I created some lessons that involved students as individuals, that didn't require physical interaction among peers and this helped some students to be more comfortable participating in the activities. With more bodily-kinesthetic experiences in my science class, the novelty of being out of their seats wore off as did the oddity of the type of instruction so classroom management issues decreased. Also, as students gained experience with the physical activities, they began to realize the benefits and so became more likely to stay focused on the activities.

By re-arranging the room I managed to minimize the need to move furniture to create open space for activities. I moved my work table to the middle of the classroom with student tables located around the perimeter. Now I only need to move the one table, at which no students are seated so they are not inconvenienced, to open the entire middle portion of the room for activities. Because student desks stay in their normal position, there is free access to notebooks, writing utensils, and writing surfaces for every student. Once the room was arranged for simplicity in obtaining activity space and clear student viewing of the activity, I was more comfortable with this mode of instruction. This allowed me to view all of the students and be spontaneous with lessons because the center of the room was nearly always available. I eventually realized that the whole body need not be involved to have a bodily-kinesthetic activity. This realization led to the allotropes lesson, shown in Figure 1, where students merely used their own hands while seated at their tables to model different structural forms of carbon.

My mentor teacher, who has used this type of instruction, has also encountered similar difficulties. He, too, found that the students became more comfortable with the instructional technique over time. He has utilized the auxiliary gymnasium and the hallway to overcome the space issue.

The third item pertains directly to my ability to create lessons to integrate physical modeling in a bodily-kinesthetic manner. I was able to design fifteen lessons for topics ranging from buoyancy to atomic theory during an eight-week instructional period. Of the lessons that were not modeled during class time, however, the majority of these could have been modeled in the class. Some activities could even be assigned as homework. The analysis of lesson plan quantity and topics reveals that I am capable of incorporating physical modeling into my science instruction regularly.

Upon reflection regarding the second research question, "will the use of physical modeling improve student comfort with learning complex science topics?" I have come to the following conclusions.

Students clearly expressed a preference for learning activities that allow them to exercise their interpersonal intelligence through group work, a definite increased comfort with visual instruction, and an appreciation for the physical activity. Physical modeling provides the opportunity to meet these student needs.

By including their bodies in the modeling, the students became involved in the teaching and learning process and were given an opportunity to relate to the presented material outside of the traditional reading, lecture, and writing types of instruction. One member of the focus group, who had not been as involved in the initial lessons, explained that some of the later activities were what he recalled to assist him on an exam.

Through discussions with students I have determined that complex instructional topics were easier for them to understand and remember when given the opportunity to experience them through physical modeling activities. Observations during activities showed that students were willing participants in this aspect of their science education, a fine indicator of comfort. Furthermore, student comments have revealed that they found the activities enjoyable and desire to have physical modeling activities remain a part of their science instruction.

A comparison of the pre- and post- instruction attitude surveys and student interviews with the focus group member displaying high initial comfort supports the use of physical modeling instruction even with students who already exhibit a high level of comfort with science. Such students were not adversely affected by a modification in the instructional technique. The focus group student maintained her comfort with science and even expressed a preference for the visual learning that occurs with the physical modeling lessons.

A variety of multiple intelligence strengths and learning style preferences were expected, and noted among the class members and the focus group. Though not all of the students selected for the focus group have a strong preference for hands-on learning or strength in the bodily/kinesthetic intelligence, the incorporation of modeling did not have a negative effect on their comfort with science. This technique did not teach directly to their preferred mode of learning, but neither was it used in isolation. Teaching through other learning styles and multiple intelligences also occurred in my classroom. By including physical modeling in my teaching techniques, I increased my ability to educate students of varying learning style preferences. Additionally, incorporating bodily/kinesthetic instructional techniques in my lessons afforded students of different learning preferences the opportunity to strengthen their abilities in this learning area.

I anticipated certain intelligence strengths and learning style preferences would correlate with surveys reflecting a positive attitude toward science. As science instruction becomes increasingly dependent upon textbook reading, I expected the hands-on, bodily/kinesthetic learners to have survey responses that were less positive than those students with logical/mathematical, verbal/linguistic, and spatial/visual intelligence strengths and auditory or visual learning styles, I found no such correlation. I have taken the surveys myself with the results that my major intelligence strengths are musical and logical-mathematical and my learning style is strongly visual. I have always been comfortable in a traditional classroom environment. Interestingly, my weakest intelligence area is bodily/kinesthetic. Focusing instruction through use of lessons centered on bodily/kinesthetic models did prove to be an interesting challenge, one that I believe has helped me to improve my abilities in the bodily-kinesthetic intelligence area. It has certainly helped me to understand how difficult it can be for some of my students to attempt to understand instruction that is not presented in a manner with which they are comfortable. The incorporation of physical modeling into my instructional technique has helped me to improve my ability to explain complex topics in a variety of ways. My students have expressed their desire to continue to have physical modeling activities as part of their science education. I have certainly become more comfortable with using physical modeling as a teaching technique.

Students were exposed to information through reading texts, physical modeling, teacher explanations, and class discussions of texts and of modeling experiences. By providing information exposure multiple times and in varying manners, I have increased the number of pathways available for memory recall. When a piece of information is presented in a manner that is comfortable for a student, they may be better able to associate this information with prior knowledge, an existing schema, thus increasing the opportunity for comprehension and long-term memory storage - a subject for future study.

Implications

The implications for my future teaching include continued assessment of learning styles and multiple intelligences of my students, not just for my information to use during classroom instruction, but for their information as well. By increasing awareness of individual learning styles, I hope to be able to facilitate formation of cooperative learning groups that have similar preferences. I also intend to use this information to assist students in planning study techniques that are of most benefit to each individual. Meeting the learning needs of my students is a constant goal. Having such specific information about the learning needs of each student I instruct will help me to move toward achieving this goal. The knowledge of student-specific strengths and preferences will be of assistance in one-on-one and small group instruction. For whole class instruction, I plan to incorporate a broad range of techniques to address the variety of intelligence areas and learning styles. This will be of benefit to my students as well as strengthen my teaching repertoire.

I intend to continue to include physical modeling in my instruction. This method incorporates several of the multiple intelligences, including the interpersonal and bodily-kinesthetic that were so highly preferred by my students. I plan to investigate the effects of this type of instruction on comprehension and recall of science information.

By sharing the results of my research with other teachers, I hope to inspire them to try a physical modeling approach in their own classrooms. The use of manipulative materials in elementary mathematics education has become widespread. We, as educators, need to consider the use of manipulative materials in other subject areas and in the middle and high school years. Allowing our students to use their own bodies for this purpose ensures they will always have the material with them should they need to revisit the subject matter. This technique should also save time (will not need to set out materials) and money since the students are provided for us in every class we teach.

Relationship of Conclusions to Professional Literature

The results of my study support the literature regarding incorporating techniques to address a variety of learning styles and multiple intelligences in education. Other research has indicated that most people prefer learning through kinesthetic instruction (Brown, 1988). I have found that most of my students (84%) possess a medium to high degree of strength in the bodily-kinesthetic intelligence. The multiple intelligence survey administered to my students also revealed that most of them have their highest strength in the interpersonal intelligence and the 96% have a medium to high degree of strength in this area. Physical modeling easily incorporates these two intelligence areas into science instruction, leading to a learning environment designed to satisfy the intelligence strengths of a majority of students.

The research of Garrity (1998) and Brown (1988) indicates that students prefer hands-on learning and that their attitudes toward a subject improve when this instructional technique is included in their learning experiences. My research supports those findings. The use of physical modeling is a hands-on approach to science instruction. The students use their own bodies as the manipulatives. I, too, have found an increase in student comfort with instructional topics when hands-on learning opportunities are provided for my students.

Physical modeling provides a way to simulate science concepts, such as atomic theory, that may otherwise be very difficult to view. This provides a learning experience that involves the spatial/visual intelligence and the visual learning style. It also gives students a tool for understanding difficult material. Orlich, Harder, Callahan, Kravas, Kauchak, Pendergrass, and Keogh (1985) have shown that such simulations are beneficial by breaking up problems into "manageable elements" (p. 307).

The benefit of providing a variety of experiences to students is clearly stated by Gardner (1995), "When a topic has been approached from a number of perspectives...more children will be reached" (p. 208). Meeting students' learning needs is supported by Jones and Jones (1998), whose research indicates that students need instruction to match their learning style. My research has shown that students have a variety of multiple intelligence strengths and preferred learning styles. By providing a variety of learning experiences involving several multiple intelligences and learning styles, I can better meet the learning needs of my students.

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Appendix A

Science Survey

(Adapted from Garrity, 1998, p. 35)

Please complete the following questionnaire and return it to Mrs. Burke. Circle "yes" or "no" to answer each question. Thank you for your cooperation.

Name ____________________ Date ____________________

1. I like science.	Yes	No
2. I think science is often hard to understand.	Yes	No
3. I think it is important for me to study science.	Yes	No
4. I think it's important for all students to study science.	Yes	No
5. I feel that science is useful to me right now.	Yes	No
6. I feel that science will be useful to me in the future.	Yes	No
7. I am looking forward to this science class.	Yes	No
8. I think this class is going to be hard.	Yes	No
9. I have trouble visualizing three dimensional objects.	Yes	No
10. I like to do hands-on work.	Yes	No
11. I like to work with a partner.	Yes	No
12. I like to work in cooperative groups.	Yes	No
13. My science homework is usually interesting.	Yes	No
14. I generally get good grades in my science class.	Yes	No
15. I have been introduced to science in the past.	Yes	No

16. What grade did you receive in first semester science? __________

17. What grade do you expect to achieve in this class? __________

Appendix B

Pre-Instruction Interview Questions

1. Why do or don't you like science?
2. Are you comfortable with the information you've been given so far in class?
3. What is the most difficult part of science class for you?
4. What have been the most enjoyable parts of science class so far?
5. What is the most comfortable way for you to learn?
6. If you could teach this class, how would you do it?

Appendix C

Multiple Intelligences Survey

(Adapted from Christison ,1998, p 160-161)

Please complete the following survey by ranking each statement as 0, 1,or 2. Write 0 if you disagree with the statement. Write 2 if you strongly agree. Write 1 if you are somewhere in between. The survey contains 42 statements for your evaluation.

_____ 1. I like to read books, magazines, and newspapers.
_____ 2. I can hum the tunes of many songs.
_____ 3. I often do arithmetic in my head.
_____ 4. I can read maps easily.
_____ 5. It is hard for me to sit quietly for a long time.
_____ 6. I am often the leader in activities.
_____ 7. I go to the movies alone.
_____ 8. I go to the library to study.
_____ 9. I enjoy talking to my friends.
_____ 10. It is easy for me to follow exactly what other people do.
_____ 11. I enjoy art activities.
_____ 12. I am good at chess and/or checkers.
_____ 13. I am a good singer.
_____ 14. I consider myself a good writer.
_____ 15. I play a musical instrument or sing in a choir.
_____ 16. I draw well.
_____ 17. I often help my friends.
_____ 18. I like to tell jokes and stories.
_____ 19. I like to put things into categories.
_____ 20. I am good at sewing, woodworking, building, or mechanics.

(appendix continues)

Appendix C (continued)

_____ 21. I can tell you some things I am good at doing.

_____ 22. I like to play number games.

_____ 23. I can tell when music sounds off-key.

_____ 24. I can remember people's names easily.

_____ 25. I like to spend time alone.

_____ 26. My friends often talk to me about their problems.

_____ 27. Movies and slides really help me learn new information.

_____ 28. I am good at sports.

_____ 29. I enjoy working with clay.

_____ 30. I often tap rhythmically on the table or desk.

_____ 31. I love to figure out how computers work.

_____ 32. I have many friends.

_____ 33. My friends find some of my actions strange sometimes.

_____ 34. I like to recite tongue twisters.

_____ 35. I learn from my mistakes.

_____ 36. I love books with pictures.

_____ 37. I often sing songs.

_____ 38. I enjoy running and jumping.

_____ 39. I have a good vocabulary in my native language.

_____ 40. I am a member of several clubs.

_____ 41. I ask many questions about how things work.

_____ 42. I enjoy putting puzzles together.

(appendix continues)

Appendix C (continued)

Multiple Intelligence Survey Score Sheet

Please write the number you assigned to each statement in the blank provided beside the statement number. Next, add the values for each column and record on the lines below the respective columns.

A	B	C	D	E	F	G
1 ___	2 ___	3 ___	4 ___	5 ___	6 ___	7 ___
14 ___	13 ___	12 ___	11 ___	10 ___	9 ___	8 ___
18 ___	15 ___	19 ___	16 ___	20 ___	17 ___	21 ___
24 ___	23 ___	22 ___	27 ___	28 ___	26 ___	25 ___
34 ___	30 ___	31 ___	36 ___	29 ___	32 ___	33 ___
39 ___	37 ___	41 ___	42 ___	38 ___	40 ___	35 ___
_____	_____	_____	_____	_____	_____	_____

Circle the column total that is the highest value. If you have more than one column with the same resulting value, circle each. The highest value correlates to your strongest intelligence area. Circle the corresponding intelligence area(s) below.

Column A = Verbal/Linguistic Intelligence

Column B = Musical Intelligence

Column C = Logical/Mathematical Intelligence

Column D = Spatial/Visual Intelligence

Column E = Bodily/Kinesthetic Intelligence

Column F = Interpersonal Intelligence

Column G = Intrapersonal Intelligence

Appendix D

Post-Instruction Interview

1. Clarify any changes in the attitude survey administered both pre- and post-instruction
2. Explain research = relate information to physical self to create an increase in the comfort with science topics.
3. Delve into helpfulness/increased comfort with science due to physical modeling examples given during instruction.
    a) Ask if student remembers any examples of this type of instruction from 3rd quarter.
    b) Give examples of lesson including physical modeling and repeat question "a" if no answer is given.
    c) Ask how student initially felt with topics of instruction (excited, apprehensive, nervous, and/or confused, etc.).
    d) Ask how the physical modeling instruction effected their comfort with the topics of instruction (less comfortable, no change, more comfortable).
    e) Ask why student thinks the lessons had the effect mentioned in question "d".
    f) Ask if student has any other ideas for implementing this type of instruction - other topics and examples of using physical modeling.
    g) Ask what the student perceives as the benefits and drawbacks of this type of instruction.
4. Ask student if they have any further comments they'd like to make.
5. Thank the student for their participation in this research.
6. If you could teach this class, how would you do it?

Author Note

Deborah S. D. Burke is a middle school science educator in Richland, Washington. This research was performed during her graduate studies at Washington State University at Tri-Cities.

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INTERACTING WITH ELEMENTARY INTERNS ABOUT THEIR PERCEPTIONS OF SCIENCE TEACHING

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Background

The theme for the 2002 Association for the Education of Teachers in Science conference suggested that there were costs associated with improving scientific literacy for global success. In our capitalistic society, the idea that "there's no free lunch" prevails. There is a price tag associated with each service and product that we receive, whether the expense is tangible or intangible. In terms of teacher preparation, Anderson and Mitchener (1994) summarized an argument that Dewey (1904) presented against teacher education in which a preservice teacher may become competent in an "immediate skill" at the cost of power to grow continually. Whatever the expense, teacher preparation programs should prepare prospective teachers to become lifelong learners and critical thinkers, a stance adopted by the Interstate New Teacher in Assessment and Support Consortium ([INTASC], 1996) and the National Science Education Standards (National Research Council [NRC], 1996). To assist elementary preservice teachers in their preparations, Bentley, Ebert, and Ebert (2000), Carin (1997), Howe and Jones (1998) and many other scholars recommend that science educators provide opportunities for reflection that lead to developing competence.

The National Science Education Standards (NRC, 1996) advocates teacher preparation that includes a wide range of activities, including those that engage preservice teachers as active learners. The instructor of the methods course met this goal by providing various perspectives on teaching science. For example, he focused on questioning skills that Carin (1997) emphasized, conceptual learning that Bentley, Ebert, and Ebert (2000) synthesized, several content standards that the *South Carolina Science Curriculum Standards* (South Carolina Science Curriculum Standards Revision Team, 1996) contained, and various teaching strategies that Howe and Jones (1998) described. In doing so, the interns had opportunity to share relevant experiences from their school sites, discuss the assigned readings for which they developed questions, and participate in elementary science activities that preceded additional discussions.

Research Questions

We collaborated to investigate three elementary preservice teachers' perceptions of elementary science teachers. Three questions guided this investigation. What images did elementary M.A.T. interns have of science teaching at the beginning and end of a science methods course? What, if any, changes did they make in their perceptions? To what sources did they attribute their images of science teaching? Even though the number of research participants is decidedly limited, their responses shed more insight on the investments that science educators should make to influence preservice teachers' perceptions. In doing so, this study provides an interpretative approach that Anderson and Mitchener (1994) say is needed to improve science education.

Data Collection Method

This investigation used constructivism as a referent for understanding elementary preservice teachers' views on teaching science. Despite the several faces of constructivism, there are common characteristics associated with this epistemology. Within the context of science teaching and learning, constructivists state that authentic learning results from the learner's active participation in the education process, connections made with prior knowledge, and manipulation and interaction with ideas and/or objects to facilitate understanding (Arons, 1989; McDermott, 1991; von Glasersfeld, 1993; Tobin, 1993; Wheatley, 1991). Therefore, knowledge is always contextual and personal (O' Laughlin, 1992; Tobin & Tippins, 1993; von Glasersfeld, 1989; von Glasersfeld, 1993; Wheatley, 1991). Information that is obtained through experiential processes is assimilated within the learner's existing cognitive schema. Inherent in the acquisition of knowledge, the learner develops the ability to interpret and apply knowledge to situations outside the context in which it was initially acquired (McDermott, 1991; Wheatley, 1991).

The research questions within this theoretical framework required in the use of qualitative research methods. The best-known components of qualitative research are participant observations and semi structured interviews (Lincoln & Guba, 1985; Bogden & Bicklin, 1992; Ely, Anzu, Friedman, Garner, & McCormmack Steinmetz, 1991). In his study of how urban middle school science teachers benefited from an intense professional development program, Carnes (1996) found that classroom teachers had difficulty describing images of science teaching within their own classrooms. Our assumption was that preservice teachers were no more articulate than those experienced educators, particularly since their experience base was more limited. Therefore, we used the Draw-A-Science-Teacher-Test-Checklist (DASTT-C) instrument as a framework in helping the research participants share their perceptions.

In the third and most recent version of the DASTT-C instrument, Thomas, Pedersen, and Finson (2001) added an illustration and narrative data component. These developers came to the conclusion that short, personal narratives might provide additional insight on certain components and aspects of illustrations that research participants drew, replacing the oral interviews that would be impractical with large groups of participants. Thomas et al. (2001) asked, "Draw a picture of yourself as a science teacher at work" (p.310). Also, the developers provided their preservice teachers with #2 pencils or markers. For our purposes, we made a slight modification to the instrument and to its administration. We made the drawing prompt less personal, asking the three participants to draw a picture of a science teacher at work. In our study, the participants used the pencil or pen that they brought to class and had 15 to 20 minutes to complete the test.

Backgrounds of the Preservice Teachers

The interns were three M.A.T. interns who were fifth year interns and had recently completed the science methods course that was described earlier. They successfully earned an undergraduate degree at the university and 18 credit hours in its Education Minor program. Meeting one of the admission requirements, these interns completed a minimum of seven semester hours of science courses offered outside of the College of Education. Each of these interns only had the minimum number of credit hours and had varying background experiences.

Betty was a white female who had negative experiences with science during her elementary and secondary school years even though she performed very well in academic areas and was in the gifted program. In the following quote, she shares her vivid memory of her dislikes for science and the experiences that contributed to them. As a result of her experiences, Betty sought opportunities to avoid taking additional science courses. Although she did fulfill the required number of science courses for the teacher preparation program, she began the science methods course with a high level of anxiety. In the following quote, she detailed her reservations.

> I wish I could stand before you and say that my elementary experiences with science were rich and fulfilling and that I developed a passion for science due to my wonderful experiences; the truth is quite the opposite. My science teachers used direct instruction. The teacher would stand in front of the class and proceed to ask us to open our textbooks to whatever page we were to be on that day and continue to read almost straight from the book. Some days the teacher would use

> an overhead projector, but most days he/she would not. No connections were ever made to my life and there was no correlation to other subject areas like math, art, literature, music, P.E., etc. I never had much experience with hands-on activities. So, you can imagine my anxiety level every year when we were mandated to enter the science fair. I felt ignorant, inferior, defeated, and utterly embarrassed *every year* [her emphasis] at the science fair. I even remember crying and begging my parents not to go to see the displays at the school because I was so ashamed.

On the other hand, Olivia, an African-American female, shared mostly positive experiences in her elementary and secondary education. The following quote serves as a summary of her sentiments.

> I have had the enlightened experience of being educated in both public and private schools in 3 different states along the east coast; Georgia, South Carolina, and Connecticut during my young life. Each experience in my science education was quite different. I had the most memorable experiences in my eight grade Physical Science and ninth grade Biological Science classes. During these two years, we spent significant time on class experiments, uncovering course content, and researching various projects.

Hal was a White male who had very positive experiences since his early childhood days. For example, his father bought him a telescope when he was very young, allowing him to explore the sky and heavenly bodies. As he related in the following quote, his second grade teacher contributed to his growing interest in science.

> My second-grade teacher was a positive influence in science teaching. She allowed me to do demonstrations for the class out of our textbooks that were normally overlooked by other teachers. She was also always willing to allow me to share any science ideas with the class.

Unlike the first two interns, Hal completed a science methods course that was designed for classroom teachers prior to his entry in the M.A.T. program. In addition, he delayed his entry into the degree program for one year, working in an observatory at the university to earn money for his graduate education. In various conversations, he consistently related his enthusiasm about science and science teaching.

Illustrations of Science Teaching

In her first drawing, Betty drew a picture of a teacher standing by a desk where two students were working. Based on the remarks in the balloons coming from the students' mouths, the students are interested in what they are doing. In her narrative, Betty stated that the teacher was allowing the students to be engaged in hands-on experiments and discoveries. The second illustration, drawn at the end of the science methods course, was similar to the first one. The teacher is facilitating the students' inquiries. Betty indicated,

> She [the teacher] was encouraging cooperative learning and conversations about science. Instead of teaching by direct instruction, the teacher is allowing her students to make connections and constructions of their own learning. There's no busy work going on in here, only valuable learning experiences that are taking place. The teacher is not telling students exactly what to do, but rather using great questioning skills to help facilitate learning.

Betty showed a few changes in her view of elementary science teaching. She made greater use of professional language in the caption associated with her second illustration. Also, her drawing had more detail. She depicted the teacher asking open-ended questions that probed thought provoking responses. The students are working collaboratively and each group has different engagements. The students are engaged and teaching themselves and their classmates. However, neither of the drawings featured teacher-centered instruction.

At the beginning of the semester, Olivia drew a female teacher who appeared to be posing for the picture, with students in the background. Her intention was to illustrate a teacher observing her students as they demonstrated how to properly measure materials and liquids. All of the students had the equipment and materials needed for this investigation at their tables and were smiling. At the end of the course, Olivia provided a new illustration of a teacher at work that was very similar to her first one, although the students were in the foreground of the drawing. It was interesting to note that both of the teachers that she drew were White, neither looking like someone who shared her African-American heritage.

In his first drawing, Hal depicted students with their teacher in the schoolyard observing stars, a comet, and the moon. There was a large telescope nearby to aid them with their observations. The students who have "!" over their heads were "inspired" while those having "?" were asking questions. The student who has a light bulb over his head has finally grasped a difficult concept. In his second and final drawing, Hal focused on the personable interactions that an elementary science teacher has with his student. While both his drawings contained an astronomy theme, the group instruction size was noticeably different. In his first illustration at the beginning of the semester, it is difficult to be able to tell whether the teacher is male or female. However, in the second drawing the teacher is decidedly a male.

Sources of Perceptions

In response to the writing prompt given with each test, the interns identified the sources that contributed to their illustrations. Although they had a good rapport with the course instructor and indicated their enjoyment of the course activities on several occasions, there were other factors and experiences that were more influential than what they drew. For example, Betty explained that her eighth and ninth grade science teachers, as well as her observations in the fall internship, helped to change her perceptions of science teachers. In the following elaboration, she shared other enabling factors.

> It is only now, after I have taken my science methods courses and read various professional publications that I have come to believe that *everyone* has a scientific mind and *everyone* can be successful if the right mode of instruction is utilized [her emphases].

As indicated earlier, Olivia had a variety of experiences with science teachers. These experiences contributed to her first illustration. At the end of the semester, she stated that, "These classes, in conjunction with my Science Methods course, helped me develop a deeper understanding and greater appreciation for science and science teachers." The classes that she identified specifically included her eight and ninth grade experiences.

Interestingly, Hal's learning experiences with his high school algebra teacher who related real world science and math applications contributed to his first illustration. It was evident that his interest in astronomy also influenced what he drew. For his second illustration, Hal acknowledged multiple experiences that framed his concept of an elementary science teacher. For example, his work with fifth graders during his fall internship and experiences with the text that Bentley et al. (2000) contributed to the following sentiment:

> I found myself desiring to show students the "why" of a concept, and found myself caring for them and their science learning. It was no longer about merely inspiring them, but wanting to know how they've changed their perceptions about a scientific concept.

Final Remarks

In summary, these three fifth-year interns had images of science teachers that were consistent with the vision of the National Science Education Standards (NRC, 1996). Specifically, the teachers in the drawings were standing beside the students (with one exception), offering guidance. The students were actively engaged in the activities, conducting investigations and collecting data. The female interns drew female teachers while the male drew male teachers. No one drew a teacher who was an underrepresented minority.

In all three cases, there were no changes in philosophical views. Each of the illustrations contained elements of constructivism that was noted earlier in this paper. There are at least two reasons for why the interns' perspectives were unchanged. As evident in *A Private Universe*, learners not only construct their own meanings, they are reluctant to release those constructions. Furthermore, the content and emphases of the science methods course reinforced the interns' views on the appropriateness of active learning and inquiry teaching.

As noted earlier, the interns enjoyed the science methods course and found the activities to be meaningful. However, their personal theories and experiences were most influential in their perception of elementary teaching. Their images of science teaching are what they think science teaching should be, regardless of their experiences. For example, Betty had negative science learning experiences. Yet, her first illustration was very different that what she experienced in elementary school. Interactions with these interns suggest that a science methods course in which students read and discuss science education issues and participate in inquiry learning activities is not enough to change perceptions, by itself. As the NRC (1996) suggested, an elementary science methods course needs to include personal vignettes, teaching episodes at a practicum site, and other activities that allow interns to be active learners. In fact, methods instructors need to use school-based experiences as the basis for preparing teacher interns and use sound scholarly material to supplement and make meaning of those experiences.

More studies are needed to identify at what costs an instructor can modify preservice teachers' perceptions of elementary science teaching through these engagements. For example, what is a desirable balance between school-based experiences and methods course activities? How likely is it that interns will modify their perceptions within a semester? For now, it seems apparent that preservice teachers enroll in science methods courses with science learning experiences and/or perceptions that are already aligned with best practice science teaching. Methods instructors must seize the opportunities to invest in these preconceptions.

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MENTORING AND CONSTRUCTIVISM: PREPARING STUDENTS WITH DISABILITIES FOR CAREERS IN SCIENCE

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Mentoring serves many purposes within the educational community. It is an avenue that can provide the support needed to meet the needs and concerns of students with disabilities. The inclusive movement, although desirable, has in many ways placed students with disabilities at further risk. Simply placing these students in classrooms with non-disabled peers does not guarantee success. They need guidance, encouragement, and assistance to counteract many of the behaviors and characteristics attributed to academic and/or social deficits. They need personalized assistance often lacking in an inclusive classroom.

Lack of motivation is often cited as a common characteristic among individuals with disabilities, especially those with learning disabilities (Gordon, Lewandowski, & Keiser, 1999) and this apathy often compromises the students' performance on school related tasks to be compromised. Just as their peers without disabilities, individuals with disabilities seek to be viewed by others as capable human beings. When others perceive individuals with disabilities as less able, they become less motivated and life becomes a self-fulfilling prophecy (King, Cathers, Polgar, MacKinnon, & Havens, 2000). Motivation is a key factor for academic success for any student (Feigenbaum, 2000). Due to the lack of successful experiences and a perception of being "different", individuals with disabilities frequently lack self-confidence leading to the vicious cycle described above. Unmotivated students eventually stop trying. This condition is described as learned helplessness. Learned helplessness among individuals with disabilities contributes to unsuccessful learning and ineffective social development. Individuals with disabilities, especially individuals with learning and behavior problems, often exhibit poor interpersonal skills directly affecting their abilities to function successfully in school and beyond (Werner, 1993). Just placing students in inclusive settings does not necessarily guarantee progress in socialization or academic success. Students need to be mentored along the way to help them break the cycle of self-helplessness and empower them to aspire towards self-fulfillment.

In their transition to adulthood, students with disabilities require learning many skills to find success in the adult world, as well as to manage their disabilities. Additionally, those who are in late adolescence are on the verge of many changes in their lives. While these adolescents have the same aspirations and hopes with respect to adult issues such as employment, social issues, and living, these issues are complicated by the disability, which often leads once again to problems of motivation (Cummings, Maddux, & Casey, 2000). These students can benefit from the assistance of mentors who can guide them and provide encouragement in the difficult transition into adulthood.

Fostering Resiliency Via Mentoring

Psychological and Social Needs

John Dewey (1938) believed in an education that would educate the whole child. Six decades later educators are still predominantly concerned with academic standards and cognitive skills. Students who fail to meet these standards are frequently referred to special education, labeled, and segregated. Negative consequences of labeling and segregating students with disabilities are self-defeating attitudes and behaviors. Adults must communicate a deep belief in their students' capacity to be resilient and support them in overcoming their difficulties through their unique strengths. Resiliency is the ability to spring back from and adapt to adversity. The literature on resiliency conveys messages of hope and success (Bernard, 1991). It challenges the notion that "high risk" youngsters are doomed to environmental and situational adversities. Adults who convey appreciation for students' strengths rather than dwell on deficits can expect cognitive as well as emotional growth. Following interviews with counselors, Ridley (1999) summarized four convictions that are crucial to believing in students' resiliency and in maintaining faith and hope in the face of adversity.

- Belief One: A belief that kindness and caring are more common and powerful than violence and hate.
- Belief Two: A belief that adults who work with youngsters must view themselves as a team of mentors or helpers who can make a positive difference in the lives of students.
- Belief Three: A belief that most individuals are survivors and are able to bounce back from adversity.
- Belief Four: A belief that human beings possess extraordinary forces that is beyond our comprehension. Individuals such as Helen Keller, Franklin Delano Roosevelt, Albert Einstein, and many others have demonstrated such extraordinary forces.

Psychologists such as Maslow (1970) and Glasser (1992) emphasize that all individuals have certain psychological needs by virtue of being human. The need for love and belonging can be met in classrooms when teachers establish caring relationships that transmit high expectations and faith in their students' resilient abilities. Mentoring can create relationships that are instrumental to building a sense of acceptance and belonging. Freedman (1996) in his book *The Kindness of Strangers* explains that the most successful adult mentors are the ones who establish friendships with young people and not the ones who sermonize and admonish. Everyone has a need for social acceptance, especially children who are in the process of developing and becoming. Social psychologists have added the social needs for affiliation, power, and achievement to the psychological needs of love and belonging (Fyano, 1980). Educators can facilitate acquisition of these social needs through inclusive education and by empowering students through interpersonal involvement and personal acknowledgement. Every student needs to be acknowledged as an individual in his and her own right. While being different from each other in many respects, each student must recognize that he/she has equal needs and rights as a person. Students can bounce back and strive for more when they are not submerged in a faceless group. The large enrollment of students in public schools is causing concern among general as well as special educators and a need for personalized learning is increasingly being heard. Ted Sizer (1999) challenges educators with thought-provoking questions:

> 'How can we make learning meaningful when our lives are so busy, our students anonymous and our curriculum cover all topics?' and
> 'We cannot teach students well if we do not know them well. At its heart, personalized learning requires profound shifts in our thinking about education and schooling." (p.6).

These questions lead to a profound shift that must be given serious consideration. Mentors can create a meaningful bond and personalize instruction for students with special needs.

Resiliency and Coping Interventions

Brooks (1999) reviewed social problems often encountered by students with disabilities. The most frequent types include: (1) needing social approval, (2) a feeling of being different or inferior which leads to low social self-concept, (3) misinterpreting cues and goals of peer behavior, (4) misunderstanding goals and consequences of their behavior and (5) failing to use social support from others. Perry and Bard (2000) identified more specific problem behaviors attributed to students with disabilities that can impair learning and block the acquisition of pro-social skills. They are:

- Low social self-concept (stigma of disability)
- Fear of bullies
- Teases Others
- Modeling negative behavior
- Social withdrawal
- Physical aggression

Successful proactive interventions must include mentoring students in social and emotional competence in order to be accepted in inclusive classrooms. Richardson (1996) emphasizes cognitive-behavioral strategies such as role-playing and verbal mediation (self-talk) to develop self-efficacy. Students with disabilities can be mentored to become their own advocates by learning about their rights as citizens and human beings. Mentoring, above all, requires a caring, trusting, and genuine relationship that encourages students to reach their potential. When students posses a sense of their own efficacy they will bounce back. In order for mentoring programs to be successful, they must be implemented systematically and include the support of all concerned parties including school personnel, families, and community based organizations.

Mentoring Programs

Involved school principals are crucial to the success of mentoring programs. Administrators must provide the support and resources necessary to accomplish the mentoring goals. Teachers along with parents have the potential to implement a successful mentoring program when the principal nurtures and supports their efforts. Noll (1997) developed a cross-age mentoring program in which ninth graders worked in cooperative learning program to teach social skills to seventh graders with learning disabilities. Results suggested that the seventh graders had an increased sense of inclusion and reduced acting-out behavior, and the ninth graders had increases in self-esteem and improved conflict-resolution skills. Sonnenblick (1997) studied middle-school girls who lacked a sense of belonging, putting them at-risk for dropping out of school and becoming involved with gangs. She instituted the Girls Acquiring Leadership Skills Through Service (GALS) Club. The purpose of this club was to involve at-risk girls in the school community and thereby increase their sense of belonging. Results suggested that students became more self-assured and mature and that they took more responsibility for themselves within the club.

The DO-IT programs for mentoring students with disabilities targets high school students with disabilities interested in careers in science, math, or engineering. Primary funding for this program was provided by the National Science Foundation. Each summer, participants spend two weeks at the University of Washington attending labs and lectures to get a feel for college life. Additionally, participants meet with faculty and student mentors, many with disabilities themselves, to learn how new technology is making it easier for them to pursue degrees and careers in fields once thought out of reach. Throughout the year, DO-IT scholars use home computers and electronic mail to communicate with one another and with mentors around the world. These cyber-relationships provide a source of encouragement and a sense of community to the students who must often overcome common challenges in pursuing their goals (Orwig, 2001).

Community service projects teaches students to transfer learned skills into practical reality. The ELF (Edward Little Franklin) Woods Project is one of many fostered by the KIDS (Kids Involved Doing Service) Consortium, a private non-profit organization. This program engages students in working to solve real-world problems in their communities as part of math, science, English, social studies, and other subjects. The projects engaged in involve many different activities and result in participants "getting involved" in making a difference, not just as a "nice" activity, but as an integral part of comprehensive planning and educational reform efforts. This process substantively addresses academic failure and lack of social bonding, the risk factors most common to substance abuse, juvenile delinquency, teen pregnancy, suicide, school dropout, and other destructive factors. In fact, research has shown that opportunities for young people to participate in the life of the community enables them to develop problem solving abilities, social competence, autonomy, and sense of hope and future attributes that enable them to "bounce back" from at-risk environments (Henderson, Bernard, & Sharp-Light, 1999).

Constructivism or Reductionism?

In science education, inquiry models are used to promote student understanding of scientific concepts and processes. Inquiry instruction is based on the concept of constructivism, which means that individuals build on their prior knowledge. The teacher is a facilitator and guides the students as they construct their new knowledge (Ward, 2001). Advantaged children have been enlightened about the natural and cultural world in their daily experiences and interactions. However, disadvantaged children and those with special needs require an explicit approach to learning because of their lack of exposure and/or learning difficulties (Hirsch & Moats, 2001). They require explicit instruction and strategies. In a review of the research, Gersten, Carnine, & Woodward (1987) evaluated six studies of direct instruction curricula and discovered that this method of teaching tends to produce high academic gains for students with disabilities and with low income students. Nevertheless, constructivist instruction cannot be dismissed for these students. Mentors can involve their charges in reductionist (skill learning, direct instruction) as well as in constructivist (inquiry, discovery) learning. Mentors can provide direct instruction and guide their protégées towards activities that promote discovery. Students with mild to moderate disabilities frequently exhibit problems with memory, attention, fluency, generalization, metacognition and motivation (Mercer & Mercer, 2001). Discovery activities in addition to direct instruction can awake the "aha" factor. Students can see the relevance of concepts being taught. When students construct learning they construct meaning. They make sense of the information provided through direct instruction. Students with disabilities need encouragement to raise their self-esteem. A feeling of "I can" can be achieved through self-empowerment and involvement. Hands-on science activities are fun and engaging. They provide motivation that, in turn, increases attention and memory retention. They open windows into the student's minds thus securing the probability of transfer and generalization of knowledge.

Discussion

There are no 'throw away' children. Each child is an individual who deserves to experience personal achievement. History has demonstrated the dangers of a "survival of the fittest" philosophy. A civilized society is one that includes all its citizens, the weak as well as the strong. We place students at-risk when we ignore their silent cries for help. Teachers must go the extra mile and beyond the normal boundaries to maximize the potential of their students. Mentoring students involves building nurturing relationships as well as guiding students toward self-sufficiency and self-management. The goal of mentoring is to eventually produce responsible and independent individuals who are able to advocate for them. Education systems must go beyond the products or outcomes of schooling and include knowledge and skills essential for socialization, citizenship, and human development. Mentoring realizes this obligation by involving the whole child in the search for "islands of competence". It involves all the essential dimensions of the human condition: the intellectual, the physical, the aesthetic, the spiritual, the emotional, and the social.

According to Freedman (1993), mentoring offers the opportunity to identify and realize our shared humanity.

> Mentoring amounts to the 'elementary school of caring' for other people's children, the children of the poor. It is a specific context in which to

> initiate the process of reconstructing empathy…Mentoring brings us together – across generation, class, and often race – in a manner that forces us to acknowledge our interdependence, to appreciate, in Martin Luther King, Jr.'s words, that 'we are caught in an inescapable network of mutuality, tied to a single garment of destiny' (pp. 134, 141).

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ENHANCING PROSPECTIVE SCIENCE TEACHERS' KNOWLEDGE OF SCIENTIFIC MODELING USING MODEL-IT

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One often under-emphasized aspect of the conduct of science associated with a better understanding of scientists and the scientific community is the role played by scientific models. The National Science Education Standards present a vision of what students need to know, understand, and be able to do to be scientifically literate at different grade levels (NRC, 1995). Among the recommendations regarding scientific inquiry, references are made to the use of models in learning science and learning about science. For example, it is recommended that throughout grades 9-12, students should formulate and revise scientific explanations and models using logic and evidence:

> Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation (NRC, 1995, p.175).

The vision of the National Science Education Standards, if it is to be realized, will require science teachers to be knowledgeable in many aspects of scientific inquiry, the role of models and modeling among them. Traditional science teacher preparation in science consists of the mastery of fact-dominated information (Anderson & Mitchener, 1994). Science process skills are typically developed through "cookbook", verification-type laboratory activities.

Do prospective science teachers know enough about the manner in which models are used in science to teach about them and engage their students in the modeling of

Do prospective science teachers know enough about the manner in which models are used in science to teach about them and engage their students in the modeling of phenomena ? We have endeavored to provide prospective science teachers with modeling experiences as learners and the opportunity to apply the knowledge gained in these experiences to the design of instruction for their own future students.

Theoretical Framework

It has been suggested that a better understanding of scientists and the scientific community will enhance an understanding of science's strengths and limitations, interest in science and science classes, social decision making, instructional delivery, and the learning of science content (McComas, Clough, & Almazroa, 1998). Assuming this is true, what knowledge and understandings must science teachers possess? Grosslight, Unger, Jay, and Smith (1991) developed a classification scheme of modeling conceptions in a study of middle and high school science students and experts. Since our prospective science teachers will someday be responsible for portraying and conveying expert-like conceptions of the role of models and modeling in science we thought it appropriate to compare their understandings to the subjects in the Grosslight et al. study. We therefore used similar questions and developed a survey that was administered to them:

I. What is a scientific model?

II. What is the purpose of a scientific model?

III. When making a model, what do you have to keep in mind or think about?

IV. How close does a model have to be to the thing itself?

V. Would a scientist ever change a model? If so, why? If not, why not?

VI. Can a scientist have more than one model for the same thing? If so, why? If not, why not?

We added two questions designed to elicit the PSTs' views and intentions regarding teaching about scientific models and modeling:

VII. Is teaching about models important in your area of science? Why or why not?

VIII. Do you intend to teach students about models and modeling? Why or why not?

It is worthy of mention that the research protocol used by Grosslight et al. employed semi-structured interviews whereas we had the PSTs respond to pre and post-instruction surveys and based semi-structured interviews of representative members of the methods class on their responses to the post-survey.

This research was guided by the questions: 1) what do prospective science teachers understand about the importance of models and modeling in science; and 2) how do their understandings change as a result of their participation in a modeling experience in an undergraduate science teaching methods course? Specifically we were interested in describing the role particular experiences, such as building and testing computer models, might play in the development of prospective science teachers' knowledge of the importance of models in science.

Context and Methods

We engaged prospective secondary science teachers enrolled in an advanced science teaching methods course in a series of modeling-related activities. Included among the experiences was the use of the dynamic systems modeling software MODEL-IT (developed at the University of Michigan's Center for Highly Interactive Computing in Education - HI-CE). We endeavored to enhance our prospective secondary science teachers' knowledge of the importance of modeling in science. The two main tasks associated with scientific modeling are model construction and model verification. MODEL-IT, developed at the Center for Highly Interactive Computing in Education (HI-CE) at the University of Michigan, is an example of a computer-based modeling tool. It is designed to support students learning about modeling: acquiring strategies for constructing and verifying models and developing skills to plan, predict, and debug them (Jackson, Stratford, Krajcik, Soloway 1995). Learners first build qualitative models, and then move to more quantitative models as they develop the necessary expertise. To support students in model construction, MODEL-IT assists the learner in making the transition from what he/she already knows of the world over to computerized model representations and establishes a bridge between simple and more expert-like representations (Jackson, Stratford, Krajcik, & Soloway 1995).

Our goal was to engage our prospective science teachers in an extended inquiry, have them build computer models using MODEL-IT, and then have them begin to consider how they might engage their own future students in modeling activities. To document the experience we videotaped all relevant class sessions and used process video techniques to capture video of the computer monitor while using the software and audio recordings of what participants were saying about they were doing. We had prospective science teachers complete pre- and post-modeling experience surveys and interviewed representative members of the class about the experience and their responses to the surveys. The prospective science teachers were also asked to write a reflective piece about the modeling experience and design a unit of study in which students would be engaged in modeling activities.

The surveys were completed electronically and responses to the same item were arranged together in tables (both pre- and post-) for ease of comparison. Interesting points requiring clarification were elaborated upon during the interviews. The interviews were transcribed and during analysis repetitive responses and those of interest were coded. Completed models, reflective writing assignments, and unit plans were collected and compared with survey and interview responses.

Analysis of Data and Findings

Research Question #1:What do prospective science teachers understand about the importance of models and modeling in science?

Scientific inquiry has been defined as the methods, activities, and progression of such that lead to the acquisition and development of scientific knowledge (Schwartz, Lederman, & Crawford, 2000). Scientific modeling is an essential component of scientific inquiry. A model of something is a simplified imitation of it that we hope can help us understand it better (AAAS, 1989, p. 168). One of the questions guiding this research is "What do prospective science teachers understand about the importance of models and modeling in science?"

In terms of the prospective science teachers' knowledge of the role of models and modeling in science, we found that most of them could be classified as Level II modelers based on the classification scheme developed by Grosslight et al (1991). Level II modelers can distinguish between ideas and/or purposes motivating a model and the model itself, and realize that the purpose of a model dictates some aspect of the form of the model. They also recognize how experimental evidence might show that some aspect of a model may be wrong and needs to be changed, and they imagine in a limited way how a model might have to be revised. Unfortunately, level II modelers see models as representations of real-world objects or events and not as representations of ideas about real-world objects or events. They also see different models used only to capture different spatio-temporal views of the object rather than different theoretical views.

An aspect of level II modelers, reported by Grosslight et al (1991) and quite prominent among our prospective science teachers was the view that models are a means to communicate information about real-world events rather than as a means to test and develop ideas or theories about the world. Analysis of the survey responses of our prospective science teachers showed that they viewed scientific models as a representation of some object or phenomena (let's use the term target) that is used by "someone who understands" the target to explain it to "someone who doesn't." The following responses are representative of many comments made by the prospective science teachers:

> A model is another way to present information so that people can gain a deeper understanding. (Bonnie-BIO, pre-survey)

> A representation of some object or process that is used to explain something. (Paul-PHYS, pre-survey)

In responding to the questions "What is scientific model?" and "What is the purpose of a scientific model?" the prospective science teachers made numerous references to models being used for pedagogical purposes:

> A scientific model is a visual learning aid of something in life that would be hard to use the actual thing in the classroom. (Claire-BIO, pre-survey)
>
> A way to show students how a scientific concept works. (Michelle-BIO/GEN SCI, pre-survey)

Models as pedagogical tools seemed to characterize our prospective science teachers' initial conceptions of scientific models even when we examined some of the questions designed to elicit their understanding of how models are built and used by scientists. This is evidenced by some of the responses to the question "When making a model, what do you have to keep in mind?"

> What the people already know and what you want them to learn from the model. (Bonnie-BIO, pre-survey)
>
> The object or principle you want to explain. (Nick-EARTH/SPACE, pre-survey)

This theme is echoed in some of the prospective science teachers' responses to the question "How close does a model have to be to thing itself?"

> Close but not as close that you could just describe the real thing. Different levels for different learners. (Michelle-BIO/GEN SCI, pre-survey)
>
> That depends on what it is being used for, a model of an atom inn third grade might be (sketched single electron orbiting large nucleus) where in 12th grade (sketched electron cloud) (Paul-PHYS, pre-survey)

With regard to the idea of multiple models, the prospective science teachers were quite confident that scientists change models and can have more than one model for the same target. Their understanding seemed to be characterized by the idea that the model is changed based on "new information" but never identified the role models play in the development of that "new information." Their conception of scientific models is that of a final form device used for communicating the explanation of something that is understood:

> Yes, they (scientists) are always making new discoveries. They better change the models to better represent the truth.(Claire -BIO. pre-survey)
>
> Of course (scientists would change a model), to change the way the thing is represent or to portray it through a different medium (Michelle-BIO/GEN SCI, pre-survey
>
> Yes, different models can present the same information in a different way. (Bonnie-BIO, pre-survey)

Of critical importance to us as science teacher educators was to determine our prospective science teachers'views and intentions regarding teaching about scientific models and modeling. All of the them indicated that teaching about models and modeling is important in their area of science. However, the *reasons* they provided to support the contention that teaching about models is important had little to do with models being central to the scientific endeavor. Instead, most of their justification centered around models enhancing student learning about scientific concepts and phenomena. Again we see the pedagogical aspects of models taking center stage:

> Yes, because models can help the students better understand concepts but the limits must also be explained (Amber-BIO/GEN SCI, pre-survey)
>
> Models of the cell, mitosis and many things that are too small to see are very important. They help students conceptualize things. (Claire -BIO, pre-survey)
>
> Absolutely (teaching about models is important). There are many times when we model cellular and molecular level events for students to better understand them. Also ecological processes are often better understood though models where students can manipulate numbers and such to see how things work together. (Ellen-BIO/GEN SCI, pre-survey)

After all the prospective science teachers indicated that it is important to teach about models and modeling, it was interesting to analyze their responses to being asked whether or not they would *actually teach* about models and modeling in their own classrooms in the future. Again, their justification was based on the idea that using models in teaching would enhance student learning:

> Yes, because I feel it is important for students to have different ways of looking at a concept. (a visual representation). (Lori-EARTH/SPACE)
>
> Yes, because I believe it will be helpful in learning the material. (Amber-BIO/GEN SCI)
>
> Yes, because I feel they are important tools to change misconceptions, allow for revealing of knowledge and great assessment tools. (Michelle-BIO/GEN SCI)

In analyzing the pre-instruction survey responses of our prospective science teachers' their understanding of scientific models can be characterized as being focused upon the types of models that are used to enhance an explanation either visually or via a tangible representation of the target. There was very little mention of the central role of models in the development of scientific knowledge. The results are not unlike those reported by Grosslight et al. in which the experts tended to talk about models in terms of actively formulating and testing ideas about reality whereas students tended to point to a more immediate transparency between reality and models (Grosslight et al., 1991, p.816). Our prospective science teachers' distinguished themselves from both the experts and students in their emphasis of the use of models for instructional purposes. Their recognition of the power of models to enhance learning of established scientific ideas is not wrong. We hoped that by engaging them in modeling activities we might expand their understanding to include an appreciation of the importance of models in the scientific endeavor.

Research Question #2: How do their understandings change as a result of their participation in a modeling experience in an undergraduate science teaching methods course?

Analysis of the post-surveys yielded two changes of note in the prospective science teachers '' understanding. First, in the pre-survey as previously mentioned, the emphasis seemed to be placed on the use of a model by someone who understands the phenomenon in question using it to explain the concept to someone who does not. In the post-surveys the emphasis shifted to the model being used by a "user" to understand the phenomenon.

> A scientific model is a visual learning aid of something in life that would be hard to use the actual thing in the classroom. A model can be scaled up or down in size in a way that it would be most useful. (Claire-BIO, pre-survey)
>
> A Scientific model is a tool or representation of a thing, process, or occurrence that enables the users to better understand the real thing. A model can be much larger or much smaller, faster or slower than what it is modeling. (Claire-BIO, pre-survey)
>
> Demonstrating a scientific concept through alternative means. (Nick-EARTH/SPACE, pre-survey)
>
> A scientific model is a representation of scientific phenomena in which variables can be manipulated with outcomes congruent with scientific data. Those outcomes can be predicted and analyzed. (Nick-EARTH/SPACE, post-survey)

The second change of note was particularly encouraging to us in light of our decision to use the dynamic computer software Model-It. The prospective science teachers used terminology in the post-surveys never mentioned in the pre-surveys used when building and testing models using Model-It such as the terms variables and relationships:

> Most likely there are assumptions made and so the model may be more of an approximation. (Heather - PHYS, pre-survey)
>
> You need to think about the different variables that exist within the system. And then you need to look at how the variables affect one another look at the relationships that exist. You will also need to get information together regarding experiments or research regarding those relationships. (Heather - PHYS, post-survey)

The prospective science teachers' appeared to be much more focused on how to identify variables and create appropriate relationships as a result of their experience building and testing models using Model-It. The next question to address is to what extent, if any, did their beliefs and intentions to teach about scientific models change as a result of their modeling experience. We were somewhat disappointed in the results in that there was virtually no change in either their beliefs about the importance about teaching about scientific models or their intentions to teach about them. They maintained their belief that models can help students learn science concepts but there were no additional references to the central role played by models in scientific research or for the purpose of testing ideas.

Our hope was to effect changes in the prospective science teachers 'knowledge of scientific inquiry via the modeling experience and although there is little evidence to suggest that this happened, there is some evidence of positive changes regarding the their beliefs and intentions regarding scientific modeling. We asked the prospective science teachers 'to write a reflection about the extended inquiry and modeling experiences using the following prompt:

> You have been engaged as learners in an inquiry project and a modeling experience. Write an entry in your reflective journals. Include your thoughts on:
>
> I. the importance of involving your students in inquiry
> II. the importance of involving your students in modeling
> III. your level of comfort in designing activities for students in which they
> IV. would engage in inquiry and modeling
> V. difficulties you perceive in engaging your own students in inquiry and
> VI. modeling

Examination of their responses were more encouraging. Many of the prospective science teachers' identified the ability computer models provide for students to quickly change variables and test the effects:

> Therefore being able to change variables and have some control over the model helps students further process the information to make it meaningful. (Ellen-BIO/GEN SCI, reflection)

> The students are able to experiment with authentic data in order to see relationships between objects. (Amber-BIO/GEN SCI, reflection)

This appears to represent a shift from their pre-survey statements. The increased emphasis of students using models and changing variables may indicate a shift toward a more student-centered philosophy.

As novice modelers, our prospective science teachers built relationships while using MODEL-IT largely based on ones they were certain existed rather than any of which they might be unsure. In this way they confirmed their level II status by not acknowledging the models utility as an idea-testing tool. While building and testing their own models, many of the prospective science teachers were amazed at the amount of background knowledge needed to expand their models from very basic ones consisting of only a few relationships, to more robust and complicated ones. This revelation seemed to convince many of them that modeling forces the modeler to know and/or learn "their stuff".

In their reflections about their level of readiness for teaching about models and modeling, many of our prospective science teachers acknowledged the importance. However, when pressed, cited time, curriculum, and technological constraints as obstacles to doing modeling activities with their own students in the future. It seems that such "time consuming" activities might interfere with what they perceive as "real content". Although we are encouraged by our prospective teachers recognition of the importance of models in science and the potential benefits of modeling activities for getting students to really think, we know we have much work to do to overcome many years of didactic instruction and long-ingrained perceptions of what is important to teach. A summary of the prospective science teachers' beliefs, based on our experience is, "Models are really important in science and if I had extra time I might have the students build computer models to see if they understand all of the terminology."

Conclusions and Implications for Science Teacher Education

The prospective science teachers with whom we worked possessed a limited view of the role of models and modeling in science prior to their experience building and testing dynamic computer models. We hoped to raise their awareness of the essential role modeling plays in scientific inquiry and to instill the belief that teaching about scientific models and modeling is important for this reason. There is little evidence to suggest that our prospective science teachers changed their beliefs about the importance about teaching about scientific models because "it's what scientists do. " There is some evidence though to suggest that their understandings about scientific models and their intentions to teach using models (instead of about models) changed. They seem to be more inclined after the modeling experience to envision engaging their own students actively in modeling as opposed to merely using models for the purpose of enhancing explanations they provide. This may represent a conceptual shift in their views about scientific models as mere representations to actual tools for learning even if they aren't aware of how scientists utilize those tools.

We have learned that with the use of the dynamic modeling software Model-It, it is possible to engage prospective science teachers in a modeling experience to achieve the purpose of expanding their understanding of the role of models and modeling. The modeling experience we provided raised the awareness of the group of prospective science teachers with whom we worked. Similar experiences may provide positive results in other settings. There is evidence to suggest that the context of a science teaching methods course may be an inhibiting factor for producing all of the results for which we had hoped. The prospective science teachers seemed much more concerned with classroom management, time and technological considerations involved in school classrooms, rather than focusing on the importance of modeling in the conduct of scientific inquiry. It may be necessary to provide modeling experiences in other contexts for this reason.

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A GAP TOO WIDE: EXPECTATIONS VS REALITY THE CASE OF A PRESERVICE SCIENCE TEACHER

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> One suspects that teachers, especially at the secondary level, are more familiar with pedagogical aspects of teaching from their apprenticeship as students than they are with the practical knowledge gained primarily from experience as a teacher. This differential familiarity is likely to affect how preconceptions and expectations operate in learning to teach (Carter, 1990, p. 307)

This case study investigates the preconceptions or beliefs about teaching and learning science that a preservice chemistry teacher brought to his 5th year teacher education program. It also describes the impact these preconceptions may have had on his beginning classroom practices in his student teaching placement, and what this teacher learned from his experiences in his teaching placement. This study is unusual because it documents the thinking and actions of a novice science teacher who decides to resign from teaching. What is especially interesting about this case is that the preservice teacher had what would be considered successful relevant prior teaching experiences, and had the support and progressive teaching expertise of both his cooperating teacher and university supervisor.

At first glance this case appears to be an outlier: a preservice teacher who had all the "right" qualifications and supportive mentor teachers decides to resign from teaching during his first placement. The findings of this study support the assertion that the "gap was too wide" between his prior knowledge and expectations about teaching science and the realities of his classroom teaching experiences.

However, there is more to this account than failed expectations, and unexamined beliefs about science teaching and learning by the preservice teacher. An analysis of this study may raise questions about how unusual this case may actually be. While this case might describe an extreme example and outcome of rigid beliefs about teaching and learning science, it might be argued that these beliefs could be attributed to this teacher's prior learning experiences in his science courses.

The Problem

One problem addressed in this study was to understand the prior beliefs about teaching and learning science that preservice science teachers brought to their 5th year teacher education program. A second problem was to understand to what extent these teachers'classroom practices may reflect a reform–oriented orientation which was emphasized in their science methods courses.

Due to the lack of information on beginning teachers' learning orientations, several studies have highlighted the need for more research which addresses beginning teachers' belief systems and their classroom actions (Simmons et al. 1999; Brickhouse, 1990), and how the learning orientation of novice teachers intersects with their preservice coursework and experiences (Geddis & Roberts, 1998). Teacher development has been a focus of science education reform efforts (National Research Council, 1996), and much research on teacher development has studied the difficulties experienced teachers have in adopting a constructivist referent for their teaching (Tobin, 1996).

These issues have been of interest to me for the past few years as I worked as a university supervisor with preservice teachers in a fifth year teacher education program. Recently these questions became even more compelling as I co-taught the science methods course as well as supervised two of these preservice teachers in their field experience placements at the same school. Teaching a reform-oriented science methods course afforded me a window into the conflicts these preservice teachers struggled with as they were presented with a constructivist educational orientation, which was not, for the majority of them, part of their prior educational experience in science. I wondered how the short exposure to these constructivist teaching approaches and understandings about how students learn in the methods course could be reconciled with the more traditional science teaching approaches which had apparently served these preservice teachers particularly well. Given the undergraduate emphasis on learning science through a traditional transmission model, I wondered to what degree could these preservice teachers be expected to "crossover " to a constructed version of learning promoted by their science methods courses.

Three research questions guided this study:

- What beliefs about teaching and learning science do these preservice teachers hold?
- What is the relationship between these teachers' beliefs about learning and teaching science and their observed instructional practices during their student teaching?
- What influences, if any, do the student teaching experiences and reflections on those experiences have on their emerging conceptions of teaching and learning science?

In this study, preservice teacher beliefs about learning and teaching science will be defined as the specific beliefs or prior knowledge about teaching and learning science that preservice teachers bring with them to their teacher education programs. These beliefs are thought to be a product of the more than 16 years that these teachers have spent in classrooms as students.

When this study began, my participants included the two preservice science teachers I supervised in their field placements at the same school. However, as this study progressed, the case of one of these preservice teachers became fore grounded due to the difficulties he encountered in his teaching placement. For this reason, the case study discussed here investigated the preconceptions or beliefs that this preservice chemistry teacher held regarding teaching and learning science, and describes the impact these preconceptions may have had on his beginning classroom practices.

Methods

The interpretive design proposed is consistent with an exploration of the learning to teach process, and is also consistent with a constructivist perspective. A case study design was deemed appropriate for this study, since it studies behavior and events in the contexts in which they occur, and considers multiple forms of evidence (Yin, 1984).

The focus of this type of interpretive study is on the participants' perceptions and experiences, and the way that they make sense of them (Merriam 1988) as they learn to teach. The meanings and interpretations of a study such as this one are negotiated with the participants since it will be the participants' realities that I will try to reconstruct (Merriam, 1988).

Program and Setting

Teacher education program

This teacher education program is a "fifth-year program" which culminates in satisfying the requirements for the provisional New York State teaching certificate. Applicants to the secondary teaching program are either in their senior year of undergraduate coursework, or have completed their bachelor's degree in their proposed teaching content area. Applicants are selected to the program based on their overall GPA, performance on subject tests in their proposed teaching content area, a writing exam, an interview with the education program staff, and an interview with faculty in their proposed teaching area.

In addition to their undergraduate subject matter coursework, these science education graduates completed courses in pedagogy such as Foundations of Education, Educational

Psychology, Science Methods, and General Teaching Methods in their first (fall) semester of their program. During their year in the Teacher Education Institute, education students completed field experiences in their first semester, and had two teaching placements in the spring semester: the first one generally in a suburban setting, the second in an urban or rural district.

During the Fall semester prior to student teaching, field experiences allowed a cohort of preservice teachers to spend time in a common placement school getting to know the school and classroom routines, working informally with students in their classroom or in remedial labs, and getting to know their cooperating teacher. Weekly field experience seminars were conducted at this site.

Research Site

The site of this study was a chemistry classroom at a large (1000+ students), suburban junior/senior high school, which borders a metropolitan district in upstate New York. This school supports a student body which is increasingly ethnically diverse, due to a movement of urban residents into the district. According to the 1990 Census, over 62% of the town's residents have not earned high school diplomas, and 69% of town households have incomes less than $40,000, with over one fifth falling below $15,000. The school website mentions that 75% of its graduates go on to college.

Participant

When he applied to the program, Ron had just completed his first year of a graduate research program in Genetics. Based on his successful past experiences as a college tutor of math and science, and as a teacher in a Research program for high school science students, Ron decided to pursue his teaching certification in Chemistry. While in the Genetics program, he had deciding against attending Medical School. He strongly felt that his long- term successful tutoring experiences and teaching high school students as well as his love of science were pointing him in the direction of teaching. In his application he described his teaching qualities as patience, scientific knowledge, and enthusiasm. Upon talking with Ron, one is impressed by his manners, thoughtful intelligence, and a genuine, likeable personality. He grew up and finished college in Kansas, after emigrating with his parents from India after completing third grade.

My experiences with Ron led me to believe he was generally representative of other preservice science teachers in the Science Methods class. He was strong in his content area, very articulate, and eager to put into practice what he had learned. One characteristic that might set him apart from others in the science methods class was that he had taken graduate–level courses in science. What I learned from Ron's journals during his field experiences was that his entries were generally focused on student behavior. He also seemed more oriented to teaching science according to more traditional versus constructivist methods, according to my observations from the Methods class, and from observations of his cooperating teacher, Lee. For these reasons, Ron was purposefully chosen so that I might study the beliefs that supported his pedagogical actions in the classroom.

The co-operating teacher, Lee teaches Honors and Regents Chemistry. She is an engaging, experienced teacher (17 years), who has a relaxed rapport with her students, high expectations for them both academically and behaviorally, and who uses elements of constructivism, inquiry, and cooperative learning in her teaching.

Role of the Researcher

My role as both researcher and as a privileged insider could pose some potential problems in this study, though I feel that my prior knowledge and relationship with Ron was more of an asset than a confounding issue, as the purpose of this study is to understand these two preservice teachers. Since the school year began, I have conducted small group classes in Field experience at their placement school. In these small classes I got to know the preservice teachers through their class discussions, weekly journals, and proposed areas of interest for a research project. Though I evaluated their work in this class, all of their work was subject to feedback, negotiation, and revision. It was possible for all students to progress to their best work. I had the same perspective on evaluation as I concurrently taught these teachers in their Science Methods course Thus I felt that my role as an evaluator of these preservice teachers' work was mainly formative, and thus the summative evaluations reflected their best efforts. This grading philosophy mitigates the possibility that these preservice teachers view my role as mainly a summative evaluator, which, I acknowledge, would have a negative influence on my ability to work with these preservice teachers in this study.

For the timeframe of this study, I acted in the role of their university supervisor, although the co-operating teacher evaluates their teaching on a day- to- day, and summative basis. While the role of university supervisor sounds evaluative, my role encompassed several responsibilities: I acted as a liaison and an advocate for these preservice teachers with their cooperating teachers and with the Teacher Education Institute, observed and provided constructive feedback on lessons, facilitated teachers' reflection on their practices, and scaffolded their learning through small group and one- on- one communications. It is actually the cooperating teachers who evaluate the performance of these preservice teachers, and their perspectives weigh heavily in deciding whether or not these teachers successfully complete this placement.

Data Sources

Data sources for the preservice teacher participant included: structured and semi-structured interviews held during the course of the preservice teacher's placement, classroom observations of preservice teachers' lessons, and examination of preservice teachers' reflections on lessons, weekly journals and/or critical incidents (Brookfield, 1994), and informal conversations. My observations of the preservice teacher's classroom actions were triangulated with the cooperating teacher's observations and reflections.

Structured and semi-structured interviews were held during the course of the placement. These were audio taped, and field notes taken as well. The first interview which took place prior to student teaching established the context for their teaching and included aspects of personal history related to science teaching and learning. Subsequent interviews focused on the preservice teacher's perception of students' learning in their classroom. A final interview at the end of the teaching placement allowed for the preservice teacher's explanation of the most important learning from their student teaching placement.

Data Analysis

In general, data were analyzed inductively using an interpretive stance (Bogdan & Biklen, 1982). The multiple data sources analyzed for this study contribute to the trustworthiness of the emerging findings.

Initially, data were analyzed by making notations in field notes and reflecting on them before writing reflective notes. All interview transcripts were member-checked. As data were gathered, I attempted to make connections among classroom observations, interviews, and preservice teachers' reflections. In this way I hoped to triangulate any emerging recurrent themes. This aspect of coding themes into categories helped to classify pieces of the database, in a categorical aggregation. This process was not linear, but was a recursive spiral, as themes were developed, interpretations were advanced, which led to more data gathering, interpretation and analysis (Creswell,1998).

Findings

While the findings of this case study may be presented as a chronology, with descriptive evidence from Ron's own words to substantiate my interpretations, in this report I will use a thematic approach to frame what I observed. However, a brief narrative of the chronology will help to orient the reader to the unfolding events of the case.

As mentioned previously, Ron' journals prior to his student teaching showed much dissonance in his intentions to teach in the reform–oriented manner endorsed by the science methods course. His microteaching lessons, which were assigned to be examples of conceptual change or inquiry lessons, were essentially didactic, despite much modeling by his teacher and classmates. His journal reflections and practice teaching were dominated by a more traditional view of the teacher as dispenser of correct knowledge.

As he began his student teaching, Ron relied exclusively on the lecture method with copious notes on the overhead, with little interaction with students. While Lee gave him many suggestions for incorporating different instructional styles, Ron did not seem willing (or able?) to try them. He believed that he had to cover certain material; otherwise the students wouldn't learn it. His students became disinterested, and as disruptions became more frequent, and Ron became discouraged, and at the same time disappointed in his students lack of effort. By the end of the first two weeks, Ron related he had trouble planning an upcoming unit: he was unsure how much he should cover, or how he was going to engage the students in the topic. It was clear that Ron needed much improvement and scaffolding in his role as a teacher, and both Lee and I attempted to help him improve by giving more specific feedback and guided instruction. Since Ron was having difficulty with framing the content appropriately, both Lee and I helped Ron organize some concepts so students could learn more easily.

My observations reinforced the fact that Ron was having much trouble with presenting concepts effectively, as well as interacting well with the class as a whole. Ron had identified poor teacher-student interactions and difficulty with planning as his two greatest problems. It seemed that these issues were definitely affecting each other. I did not understand then why he was not communicating these concerns with Lee; she seemed to genuinely want to help him. In fact, Lee and I collaborated on a specific plan to help Ron build the skills he needed, as well as address some of the classroom dynamics. We both agreed that Ron had potential, and genuinely seemed to work well with the students on a one-to-one basis. After six weeks of student teaching, Ron told Lee that he was unsure of continuing in the program. After a very effective direct interactive lesson which engaged the students, Ron told me that he needed to give serious thought to continuing. Lee called me after a weekend to tell me Ron had notified her that he was resigning from the teacher education program.

Analysis: A Gap Too Wide

Ron agreed to talk to me about a retrospective on his student teaching experience. What I learned from this interview as well as the talk we had on the day of his last lesson, helped me to understand how a gap between Ron's expectations of teaching and the reality of the classroom was too wide for Ron to bridge in the short time frame of this teaching placement. This caused Ron to resign from teaching in what he called "an efficient decision."

What he meant, as he explained it, by "an efficient decision" was that he made the smartest decision about teaching, given what he had learned, in the least amount of time. Ron had learned a great deal about good teaching, students, and ultimately about himself in the context of teaching.

Good Teachers and Teaching

One apparently large gap was between the "good teacher" Ron had as a role model in high school, and the new "good teacher" he perceived in Lee. Ron's model for a good science teacher who was most effective for him was his high school chemistry teacher:

> I liked this teacher because he was so structured: he had all his notes on an acetate roll for the overhead, and class was always the same. He would talk and we would copy down the notes and study them later. I liked this teacher because he was so structured-then we would know what we have to know for the test. (Ron, Int 1)

In other interviews, Ron described his best teacher as "strict, in control, and authoritarian". He described this teacher's classes as "quiet and not disruptive", in contrast to his perception of some other science teachers' classes in the same building. All his science teachers, according to Ron, relied exclusively on the lecture method of "transmitting" scientific knowledge, and he acknowledged that this teaching approach continued in his college classes:

> In high school, it was just mostly just about being a good listener to teacher talk. The teacher sometimes did demos, but mostly we sat around listening. I sat in class and tried to absorb it, and then we'd do problems for homework, and go over them the next day. (Ron, interview 1)

Ron was observed trying to be that "good teacher" of his high school days, but this approach was ineffective with his students. Ron's beliefs about teaching and learning based on his high school experiences were apparently reinforced by his successful experiences of tutoring science and math in college. In fact, he expressed confidence in his "effective teaching abilities: patience, intricate knowledge of the content area, and the ability to pinpoint concepts that are exceptionally difficult for students and to address these concepts." Tutoring appeared to be a teaching referent that reinforced Ron's view of teaching as a traditional knowledge transmission exercise. In his view, teaching was effective to the extent that the content was clearly explained so it could be understood. Thus the authority of the teacher as knowledge transmitter is maintained.

In contrast, Ron's cooperating teacher, Lee, had what could be described as a progressive approach to the teaching of chemistry. She used various instructional styles and activities to engage the learners in making sense of her lessons. She frequently used cooperative learning activities, and involved the students in self-assessment. Lee was perceived by Ron as a good teacher because she had a respectful rapport with her students, was engaging, and appeared to be decisive and efficient. I observed Lee working with a diverse group of learners by varying instruction to meet students' needs. Many times Ron said that he could not envision himself teaching like Lee. Her wealth of knowledge about teaching caused him to state on many occasions " She's amazing, I don't know how she does it." Ron expressed the belief that he lacked the "talent" to be like Lee, and did not believe he had the time to develop the skills of what I call his conception of the "new good teacher", as exemplified by Lee.

Learners of Science

Ron also perceived a great gap between the students in his classroom, and his own experiences as a student of science. It quickly became apparent during his student teaching that the expectations Ron held for learners in his classroom were unrealistic, and based upon his own experiences as an expert learner of school science. The finding that a preservice teacher used his own experiences as prototypical and generalizable, has been previously reported in the literature (Holt-Reynolds, 1992). In his words Ron was "good at science", he was a successful negotiator of school science.

> I was good at science--I could listen and remember things easily. It was lecture format with cookbook labs. The labs were so structured that if you paid attention you could do the lab and get full credit for it without even going into the lab. In fact, many

> students, myself included, did our labs this way. That way we got full credit (Ron, interview 1)

Ron did what was expected of him in learning school science. His emphasis on full credit, and knowing what to know for the test indicate that he was a student to whom performing well and grades were very important. He was individualistic in his approach to learning. He related that he never worked with other students when learning concepts. This was not surprising, given his emphasis on performing well and grades, and the competitive culture of school science.

Ron learned best by listening in lecture, and reading the textbook. He considered himself very successful at school science: his style of learning: listening to the teacher and studying the text, and the traditional approach to teaching science as a body of knowledge by his teachers ensured that he would be successful.

In contrast, Ron's students were not like him. He was unable to deal with what he perceived as the diversity of effort, motivation and behavior in his classes. He acknowledged that he was "naïve", that he thought, "that students would be like him, and want to learn," and care about high grades when he began his student teaching. The students may have wanted to learn, but Ron only gave them the opportunity to learn his way. And that was not the way of most students in these diverse classes. Instead of high grades, Ron found most students content with only passing, which discouraged him. These students did not share the same values for learning science that Ron had as a high school student, and he felt distanced from them as a whole. Some of these gap issues may have made Ron feel he was in a "foreign culture" in the classroom. He perceived himself as an outsider: he felt had little in common with the expertise of Lee, nor the students in this science classroom, who he believed, lacked learning goals.

The wisdom of authority vs. the wisdom of experience

Learning to teach involves much more than using what has been learned during educationl and prior science course work. That learning relied on the authority of position and reason, but learning to teach relies most heavily on learning from the *experiences* of teaching (Munby & Russell, 1994)

As a science student, Ron relied on the authority of position of teachers and the text. This learning orientation had served him well in negotiating school science, where teachers were the experts, and learning from texts supported a model of science as the learning of content. In this view, teacher as expert also had a strong evaluative role.

Since Ron's previous learning orientation involved figuring things out for himself from books, and working by himself, it seemed that this orientation was counterproductive in learning to teach. In one example he asked me for books on classroom management, instead of accessing the practical knowledge of his cooperating teacher who knew the needs of her students best. In another example, Ron recounted that his whole problem with student teaching was because he had not set his classroom up correctly according to the recommendations of Wong & Wong (1994), and thus it was impossible to have authority in someone else's classroom. Being in a position of authority in the classroom was important to Ron, he said. At the beginning of his. . program year he stated, " I want to be a teacher the students respect and learn from. "

Because of his view of teacher as authority figure and evaluator and his individualistic nature, it appeared that Ron had much difficulty communicating with Lee, whose teaching expertise intimidated him. By asking for help from her, he perceived that he would be evaluated as deficient in aspects of teaching or content. What Lee expected was that he would see her as a coach, in a collaborative role. It seems that his previous beliefs and experiences as a student interfered with his ability to learn from experiences in the classroom, as well as communicate effectively with his cooperating teacher

What Ron learned through his experiences in the classroom, was that teaching was more than trying to apply propositional knowledge from books, or course work, nor was it like explaining in tutoring. Learning to teach is situation and context specific and involves learning from experiences in the classroom. Ron was unable to modify his beliefs about learning and teaching based on the new experiences he had in the classroom while he was teaching. He appeared unable to adjust his teaching role by learning from experience.

Discussion

Is there more to Ron's account than failed expectations, and unexamined beliefs about science teaching and learning? An analysis of this study may raise questions about how unusual this case may actually be. While this case might highlight an extreme example of rigid beliefs about teaching and learning science, it might be argued that these beliefs may be attributed, in part, to Ron's prior learning experiences in his science courses.

A lens through which this case may be viewed is in terms of the prior science learning experiences of the preservice science teacher. Two frameworks: the algorithmic learning orientation (Geddis & Roberts, 1998) and the cultural myths of teaching science (Tobin & McRobbie, 1996), may be useful in helping to frame the case of Ron.

Geddis & Roberts (1998) define learning orientation as how a preservice teacher thinks about teaching and learning. They argue that the undergraduate science experience of many science teachers promote a learning orientation which is algorithmic. This orientation "assumes: there are right answers, science has reliable problem solving algorithms for yielding those right answers, and science learners need to master those algorithms" (Geddis & Roberts, 1998, p 272).

This orientation is probably more typical for the physical sciences, where solving of textbook problems is a predominant learning approach. While learning some scientific knowledge is amenable to this approach, learning to teach science is not algorithmic. These authors claim that this orientation could get in the way of learning to teach, as the novice teacher needs to be able to learn from experiences in their classroom, according to the knowledge in action of the competent professional (Schön, 1987).

In their work, Geddis & Roberts (1998) explored the beliefs of Kevin, a preservice physics teacher, during his student teaching placement. I found many similarities in thinking in the cases of Ron and Kevin in studying this work. Both preservice teachers saw their subject area teaching as unproblematic for their students (since it was easy for them). In one excerpt, Ron comments on a state chemistry exam "as I looked over the exam, I realized that Part I is not very difficult. You can easily figure out the answers by just thinking things through." Ron thought that the chemistry content of his course was simple: All the students needed to do was think about it, and it would become clear to them.

Several other similarities between these two preservice teachers were noted. Both believed in giving their students "the basics" on notes as an instructional method, both were shocked by the apparent shortcomings of their students in learning from lecture, and both related classroom management problems with disinterested students as a major concern. These authors claimed that Kevin had "considerable difficulty" in conceiving of other perspectives on teaching, "instead his focus was on finding the definitive, almost algorithmic knowledge about pedagogy, parallel to what he sees as his definitive subject matter knowledge". (Geddis & Roberts, 1998, p 288).

The description of an algorithmic learning orientation seemed to fit Ron as well. Instead of learning from his experiences in the classroom with the help of his cooperating teacher, Ron tried to find algorithms for classroom management from books. He was also focused on the one "correct " way to teach a particular science lesson. Ron related that a "good" lesson had to convey the content in an efficient manner, with no wasted time.

In another similarity, both Kevin and Ron viewed their students' learning efforts as problematic. In this excerpt Ron talks about his students:

> I am surprised by the fact that students have changed so much since I was a student. They have become very dependent. Everything has to be handed to them, and most don't make an effort to learn anything. (Ron, student teaching)

Geddis and Roberts link an essentialist view of *learning* science to the same perspective on *teaching* science. One particular explanation by these authors of Kevin's thinking seemed to resonate strongly with Ron's case:

> Consequently when telling is unsuccessful in terms of classroom management and conceptual understanding, this experience is attributed to learner character and preparation (p 289 Geddis & Roberts, 1998).

These similarities and consistencies in the thinking of two preservice physical science teachers from two different case studies tend to reinforce the idea that prior science learning experience may predispose the thinking of these physical science teachers in similar ways.

Another frame from which to view Ron's case is Tobin & McRobbie's view of the cultural myths in the teaching of science (1996) This frame shares several assertions of Geddis and Roberts (1998). According to these authors, the culture of science teaching in schools is dominated by several "myths" or norms which are supported by the school community and which in turn, shape the beliefs and actions of the school community. According to Tobin & McRobbie, the culture of science teaching in schools supported the teaching of science as transmitting a body of knowledge to the learners, focused on the efficient preparation for end of year tests, and emphasized the rigorous and declarative knowledge of science curricula (Tobin & McRobbie, 1996).

What is disturbing is that the preservice teachers who come to a fifth year teacher education program have succeeded and thrived in this school science culture, and perhaps even wished to become science teachers based on their perspectives as science students. If aspects of both of these models of science learning combine to influence the preservice science teachers prior knowledge about learning and teaching science, it is unsurprising that the learning to teach process is problematic for many science teachers.

In a time when the need for science teachers is great, and the call for reform in science education is a priority (National Research Council, 1996), it is important that attention is paid to the previous learning of the preservice science teachers and how this learning may intersect with their teacher education programs. More than addressing the theory -practice gap between teacher education coursework and teaching experiences in the schools, the study of how previous learning approaches in the science content area may help or hinder the learning to teach process seems to be an intriguing area of future study. The findings of this case study add more evidence to the recommendation that teacher education programs be built on preservice teachers' beliefs and prior educational experiences (Wideen, Mayer-Smith and Moon, 1998, Pajares, 1992) and especially how the learning orientation of novice science teachers interacts with their preservice coursework and experiences (Geddis & Roberts, 1998).

In addition, the findings of this study also invite the consideration of a metacognitive approach to learning to teach consistent with Munby & Russell (1994). Consistent with a constructivist view, teacher educators may facilitate the self-examination of preservice teachers' propositional learning orientation in order to facilitate the necessary learning from experience in their teaching placements.

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IF INQUIRY IS SO GREAT, WHY ISN'T EVERYONE DOING IT?

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The educational adage that teachers tend to teach the way they were taught can be either positive or negative depending on the nature of the teaching they have experienced. Traditionally, science has been taught in a manner in which students passively listen to teachers lecture or read and answer questions from a textbook (Weiss, 1987). Many science teachers end up teaching this way because they were not modeled other methods of teaching (Bryan & Abell, 1999). One method of teaching science that has gained considerable ground in the past ten years is the use of inquiry to make science a more hands on and minds on endeavor. Even though the idea of teaching inquiry has been around since the early 1900's (DeBoer, 1991), implementing inquiry into the classroom has proven to be a challenging task for teachers at all levels.

Pre-service teachers generally experience scientific inquiry for the first time in their science methods courses in college (NSTA Reports, 1996). The problem persists that if pre-service teachers have never been exposed to inquiry then they may be uncertain how to teach using this method (Stake & Easley, 1978). Lee, Krapfl, & Steffen (2000) conclude from Fosnot (1989) that teachers are a product of an "educational system where they have acquired twelve to thirteen years of passive listening and regurgitation followed by more years of post-secondary school refining these skills" (p. 635). If this is the case then it is unrealistic to expect pre-service teachers to know how to teach inquiry based on one science methods course taken in undergraduate school.

Pre-service teachers may have a conception of how students learn based on their own experiences (Mellado, 1998). If these experiences have been negative then teachers may perpetuate negative connotations of science or, worse, they may decide against teaching science altogether. In order to break the cycle of traditional teaching, teachers will have to experience learning in the way they want their students to learn (Loucks-Horsley & Stiegelbauer, 1991). Teachers must be able to think in a different manner than the way they were taught (Broko & Putnam, 1995). If pre-service teachers tend to teach the way they were taught then science educators should be prepared to model inquiry.

Methodology

The subjects of this study were pre-service students enrolled in an elementary science methods course (n=48) at a large Mid-western university during the spring semester of 2001. The group of junior level students comprised of 43 females and five males. Most of the pre-service teachers' background in science consisted of an introductory course in physics, in chemistry, and in biology. This elementary science methods course is the only science methods course required of pre-service elementary teachers. A field placement experience accompanies this course.

As part of the early field experience, pre-service teachers spend one day a week for four weeks teaching science to elementary students. Pre-service teachers spend three hours during each visit to the school in which 40 minutes is allotted for science lessons. Several pre-service teachers are assigned to the same classroom and teach groups of four-five elementary students. Their science lessons were structured according to the 5E learning cycle (for information on the 5E learning cycle refer to Bybee, Buchwald, Crissman, Hell, Kuerbis, Matsumoto, & McInerney, 1989), which stretched over one day a week for four weeks.

This study compared pre-service teachers' beliefs about inquiry before, during, and after their field placement experiences. One of the expectations of their science field experience is that they will use an inquiry-based methodology to teach a science lesson. This is consistent with the National Science Education Standards, which states, "Teachers of science plan an inquiry-based science program for their students" (NRC, 1996, p. 30).

As the instructor of this elementary science methods course, the pre-service teachers had been exposed to inquiry-based methods during their elementary science methods class in which they were concurrently enrolled. This introduction to inquiry consisted of discussions about question and answer techniques, ways to engage students, how to help students conduct investigations and explain their findings, ways to relate the lesson to everyday life as well as strategies for assessing students by using journals, portfolios, rubrics, and discussions. The instructor and the class discussed ways to make lessons more inquiry-based but we did not formulate a definition of inquiry.

The main purpose of assessing their conceptual understanding of inquiry is so I would be able to see how they were constructing the pieces of their inquiry puzzle. I wanted to know what they believed about inquiry and how they defined inquiry. Authentic assessments in the form of reflections revealed how pre-service teachers conceptualized inquiry and the kinds of activities/questions they believed constituted inquiry.

The first reflection occurred after discussions about inquiry strategies but before their first field experience. In this reflection, teachers described their concerns and perceptions of inquiry. Over a period of four weeks during their field placement experiences, pre-service teachers reflected on their teaching experience, paying careful attention to identifying instances of inquiry. At the end of four weeks, pre-service teachers compared how their definition of inquiry had changed over their four-week experience. Their conceptions of scientific inquiry at the beginning, during, and after their field experience provided insight into how they defined inquiry and how they viewed inquiry taking place in the classroom. I looked for patterns in their journal responses concerning students' conceptions of inquiry as they progressed in their teaching using this unfamiliar method.

In summary, pre-service teachers reflected on a definition of inquiry before their field placement experience. In the second reflection, pre-service teachers provided instances of inquiry occurring in the classroom. In the final reflection, pre-service teachers compared how their definition of scientific inquiry had changed over the course of their teaching. All three reflections consisted of journal entries.

Results

Prior to field placement experience

Initially, many of the students felt scared and nervous about teaching scientific inquiry because they had never experienced this method as a learner. Pre-service teachers expressed fears about teaching an approach that few used, and one that most had not experienced.

> The question of inquiry is not an easy one. My lack of experience coupled with my limited exposure has left me questioning the entire method.

In their reflections, students speculated on reasons why practicing teachers adhered to traditional ways of teaching. Some pre-service teachers described inquiry as time consuming and difficult to teach because the teacher has to leave everything up to chance. Practicing teachers may lack confidence in the subject matter and may also feel they will lose control of the classroom.

Most pre-service teachers had not experienced inquiry methods during their schooling. Their first exposure to scientific inquiry was the elementary science methods class in which they were concurrently enrolled. This lack of inquiry modeling is evident by their reflections.

> I did not have much experience with inquiry throughout my schooling. I know most of my science classes in junior high and high school consisted of looking up a definition and answers to questions.

When defining inquiry, pre-service teachers focused on the role of the teacher in the inquiry process. Most students described the role of the teacher as a guide or a facilitator. Pre-service teachers did not describe what the teacher actually did in these roles but later reflections revealed that they were initially confused about what the teacher was supposed to do as a facilitator.

Several pre-service teachers mentioned how the teacher should create an environment where students feel comfortable asking each other questions without running to the teacher to find the answer. If students rely on teachers for the answers then they will think there is only one right answer when there could be several explanations. Because students are not told exactly what to do, they discuss possible answers with classmates and refer to resources. Teachers should not give students the "right' answers but rather help them find the answers themselves. The students can develop their answers through cooperative learning.

Many pre-service teachers felt students gained leadership skills, independence, and a sense of ownership by relying on resources other than the teacher. In this learning environment, students look to one another for information. Students who know where to look for the answers to questions develop skills for lifelong learning. These pre-service teachers recognized the importance of helping students to become scientifically literate.

> We inquire when we do not know the answer. We choose to investigate until we get the answer or an understanding of the issue using a variety of resources. Students will continue to enjoy learning later in life. Lessons with clear, straightforward instructions do not let a student imagine and grow; they just learn to listen.

The collection of responses on conceptions of inquiry is much richer than any definition I would have given them. Below is a compilation of excerpts from the reflections of twelve students. Together these provide a rich insight into the meaning of inquiry.

> Inquiry is a "live" approach to teaching if you will. Teachers who use inquiry don't necessarily know what questions their students will have, or what ideas they will want to test. The inquiry method is not something that you can Xerox or check with an answer key. What I like best about the inquiry method is that it requires teachers to learn along with their students. Inquiry is a way of teaching science where we relate what is being taught to actual occurrences in the world around us. I have come to believe that inquiry is the process of trying things out, asking questions, and learning from personal curiosity. Inquiry-based learning involves fewer concepts, but more in depth coverage of those concepts. Students decide what sparks their interest and use that spark to light a fire. In inquiry, the students structure the class with their questions rather than the teacher leading the class with answers. Teachers encourage students to expand on their ideas. Inquiry allows students to do experiments without knowing the outcomes prior to beginning. Students have more freedom to participate and take ownership of their learning. Students are given the opportunity to apply their knowledge with inquiry because they are expected to investigate in a way that makes sense to them rather than to the teacher. The entire point of inquiry is to find out something you did not know.

Inquiry touches many aspects of the classroom- the role of the teacher, the level of student participation, how a science investigation is conducted, the skills students develop that can be applied outside of the classroom, the arrangement of materials and the room, how students interact with each other and the teacher, and how students learn.

During field placement experience

Students provided many instances of inquiry moments during their field placement experiences. Though some of these experiences may not be considered inquiry by some, it is important to highlight the types of activities pre-service teachers considered inquiry-based. Simply providing a definition of inquiry does not capture the nature of inquiry; these examples put inquiry into a meaningful context.

> Soon all of the children were jumping on their ice to make it smaller. It was great to see their minds working. When one idea didn't work, they deduced how to solve the problem in an even better way, which is the true meaning of inquiry. All in all though, it was a nice activity, which got children thinking and problem solving, which are two main goals of science inquiry.

Pre-service teachers expressed surprise at students' ingenuity when students were given freedom to express themselves. I could have just told my pre-service teachers how inquiry encourages creativity but for them to see it for themselves proved very rewarding for them.

> I knew right off the bat that inquiry was taking place because students were asking themselves and others questions about what they were going to construct. Each student had an idea to add, and the products being created were absolutely magnificent. It was so neat to see the students work together so well, and to hear one exclaim, "Hey, I've go an idea!" I knew that kids were creative, but I was blown away by this much creativity and imagination. The explanations for the work of the machines ranged from a trash-collecting machine to a lightning catcher. The kids explained every detail down to how the machine would come packaged if purchased. I thought it was neat how students in the audience had ideas for the students presenting.

Pre-service teachers grappled with the amount of independence to give their students while working on projects. They discovered that teachers have to constantly monitor the students to figure out when to step in to clarify or redirect the class.

> I was afraid to show them how the pulleys worked because I feared they would not come up with different ideas on their own. But after I saw the frustration in

> their eyes, I brought them all together and showed them how the pulleys worked. I learned that you do not have to leave out instructions or explanations to make inquiry occur. The students must have enough background to work by themselves.

In another classroom, the pre-service teacher monitored the classroom and decided the students did not need additional explanations. The teacher could take a step back and let the students continue. Each classroom may be different in the amount of direction the students need to successfully complete investigations.

> I could tell that inquiry was taking place because I did not offer them explanations; instead, I allowed them to answer their own questions and make their own comments about the objects. They reached conclusions on their own, which was amazing for me to see.

Not only did students benefit from inquiry methods but pre-service teachers learned along with their students. At times, teachers reflected how initially they did not know the answer to a question but when the class explored the question, the students and the teacher marveled at their discoveries.

> We were looking at whether things floated or sunk [sic] and we were trying out different objects like paperclips, rocks, corks. One student was noticing a pencil, which had been sharpened so many times that the pencil was very short. He asked if he could put this object into the water. I figured the pencil would float. I mean it is wood and all but to my excitement, and to his, the pencil stood vertically.

After field placement experience

Several pre-service teachers confessed during their final reflection that they were more skeptical about teaching inquiry than they had let on in their first reflection. During their first reflection, perhaps they were uncertain what to fear and, thus, had difficulty pinpointing the sources of discomfort. The realization of the their apprehension to teach inquiry to their renewed interest in understanding inquiry allowed them to see their growth.

> At first I was a little leery about this method. I was confused. I did not understand how this could be successful learning for the students. To be honest, I thought the whole process was a waste of time and in no way would it work for these kids. But after experiencing it for the first time, I saw inquiry in a different light. They shouldn't expect the teachers to spell out everything to them. It seems more beneficial to the students when they learn things on their own, through questioning and exploring methods. I like how students are allowed to have independence while they are learning.

They also held misconceptions of inquiry that were not easily identified in the first reflection. Pre-service teachers confessed that they thought inquiry was completely student-based or rather student run.

> I am happy to write this reflection because I have had a change of heart about inquiry-based teaching and learning. When the idea was first presented, I, like many others in our class, was very confused and scared of inquiry. I thought that inquiry was completely student centered and consisted of a teacher turning her students loose with random materials that they would hopefully learn from. But, as I began to write my own unit and as we completed more activities and experiences in class, my definition of inquiry began to change.

> Before entering this lesson, I felt that inquiry was something completely arbitrary with no clear guidelines or lessons. I was afraid of inquiry because I felt that I would have no control over the students and what they were doing in the classroom. I was afraid of what might happen to the structure of my classroom if I attempted to teach my students through an inquiry-based method. Now that I have faced these fears, I can honestly say that I have learned a great deal about inquiry and am not afraid of using it in my classroom.

Misconceptions about who had control in the classroom led to confusion about the role of the teacher. If the teacher is supposed to be a guide, what does the guide do? Some pre-service teachers adjusted their definition of inquiry to include the changing role of a teacher during the inquiry process. While students still described the role of the teacher as a facilitator or guide, they also expanded the role to that of mediator, consultant, and coach.

> In the example of making slime, the kids came up with specific questions and tests that they could perform in order to see what the substance was. In an activity like this, the teacher is the facilitator. I was there for guidance and to help them

> figure out where they wanted to go with their experiments. At the end, I was a mediator as the kids shared their information. I think kids will need lots of simple inquiry activities to prepare them for doing large inquiry lessons.

Another misconception that surfaced in the final reflection was that inquiry was too time consuming and difficult. After teaching inquiry, some pre-service teachers described how the preparation for an inquiry lesson is extensive but once the plans are made, the students become active participants in their learning by asking questions, experimenting, researching, communicating with peers, and drawing conclusions. Once the pre-service teachers saw how the students assumed an active role in their learning, they could see that though inquiry may require more time in preparation and structuring the lesson, the teachers took a step back and let the students generate ideas, discuss options, make decisions, choose materials, generate results, and share new findings.

> My definition of inquiry no longer includes tons of hard work devoted to the entire unit. After using this method, I have seen that the hard work on my behalf only involves writing the lesson.

Because students share a greater responsibility in their learning, several pre-service teachers discussed how students also gained self-confidence by being able to solve problems on their own.

> The main point of inquiry-based learning is that children are responsible for some part of the learning on their own. They must learn from an early age how to find things out for themselves. If we give the students this key then they will be much better learners in their futures. By doing this early, when they are older they will know where to look when they need an answer and will not feel like learning is impossible. This is a key that we can give children and we should give them to better their futures.

Inquiry is a key to unlocking knowledge. The skills children develop through inquiry help them access information that they might not have been able to. If the teacher or the textbook is always providing children with information and never teaching them the skills to find the answers then children are limited by what is presented to them. They may not know how to open the door to expand their thinking.

Through these reflections, pre-service teachers described their conceptions of inquiry and provided examples of inquiry experiences. The most notable difference in conceptions of scientific inquiry over the four-week period was not that their definition of scientific inquiry changed but that their attitude toward teaching it had. Many stated that instead of changing their definition of inquiry, their definition expanded, became clearer, or held deeper meaning for them.

> Throughout this unit, my definition of inquiry has not necessarily changed, but my attitude towards it for sure has. Initially, I was nervous about inquiry-based activities. It was and probably will be hard to take a step back and let students figure things out on their own, rather than just telling them the answer, but that has become easier for me. All in all, I feel much more comfortable using inquiry-based activities in my classroom and actually plan on trying to use the method a lot. I like the way students are teaching themselves in a way, because it will help them remember things better and also to become interested to pursue future learning.
>
> My definition hasn't necessarily changed, but it has expanded to a more meaningful definition. So my definition of inquiry is that children need to grow knowledgeable through using previous knowledge, asking/answering questions, exploring or self-discovery, sharing ideas, and communication. This is all in my previous understanding of inquiry, but actually doing it compared to only reading/hearing about it, has given me a clearer understanding of the importance and effectiveness it has.

Perhaps one of the most indicative responses that let me know their inquiry lessons had been successful was when a student wrote, "I wonder if other teachers know about inquiry. If they did, they probably would use it." These are testimonials of pre-service teachers; many who had never heard of inquiry much less experienced its use as learners themselves.

Discussion

In the first reflections pre-service teachers described being nervous and scared to teach inquiry. By their final reflections, some confessed that before they had taught using inquiry, they initially felt inquiry was a waste of time and questioned the effectiveness of this method. When I first presented inquiry to the pre-service teachers, I expected them to be nervous about teaching. What I didn't expect to see revealed was the resistance pre-service teachers felt toward teaching this seemingly new approach. They questioned the usefulness of inquiry and how it could be used to enhance science learning. I am glad I didn't tell them inquiry had been around for 100 years already without wide acceptance.

I should have expected my pre-service teachers to go through a period of "disequilibrium" because they were in the process of constructing new models of teaching and trying to fit them into their educational schema (Piaget, 1975). Christopher Day (1999, p. 55) cautions that "teachers who are reflective inquirers need to recognize that inquiry is likely to raise issues of change and that will involve a confrontation of inconsistencies with/in and between existing core values." What need to be in place are support structures for teachers whose previous conceptions of teaching have crumbled.

The results of this research support Rankin's identification of common inquiry misconceptions (2000). Though some of the misconceptions Rankin addresses were not reflected in this study, other misconceptions not identified by Rankin surfaced. These misconceptions included the amount of time involved in preparing inquiry based lessons and the notion of a disparity between the scientific method and inquiry. This study provides a research basis for some of Rankin's assertions about inquiry misconceptions.

Some of my students were so convinced by the success of their inquiry experience that they stated they would use inquiry all the time. Rankin reminds educators that in the push for more inquiry based activities that other educational methodologies should not fall by the wayside. Teachers should be equipped with the knowledge to make decisions about which methods fit certain concepts or objectives.

One misconception that Rankin identified, which I did not account for during my teaching of inquiry to pre-service teachers, is that "all hands-on is not inquiry; not all inquiry is hands on" (p. 34). I believe some of pre-service teachers still believe this misconception because I did not highlight other ways to do inquiry. In class, we mainly focused on how activities could be more "hands on" rather than discussing how the process of finding an answer through research could also be considered inquiry.

In further support of Rankin's identification of misconceptions, my pre-service teachers also had misconceptions about questions having multiple answers. Many of them had experienced in science class only right or wrong answers. As they facilitated inquiry investigations with their students, they began to see how questions could have multiple answers. Students could take different approaches to problems that resulted in multiple outcomes.

Rankin has also encountered the misconception that inquiry teaching is chaotic. In fact, inquiry teaching involves a "high level of organization, planning, and structure" (p. 36). Students didn't realize some of their misconceptions until after they had experienced inquiry and had gotten a sense of how inquiry worked. Initially, pre-service teachers felt the teacher relinquished control of the class and let the "students take charge of their learning." This is a common phrase used to describe the students' role in an inquiry classroom. However, to a teacher who is unfamiliar with inquiry, this sounds as if the teacher is not in charge.

In addition to Rankin's description of inquiry misconceptions, pre-service teachers' reflections also indicated others. In their first reflections, some pre-service teachers expressed concern over how much time was involved in inquiry lessons, and that inquiry required a lot more time and effort than other strategies. Some pre-service teachers even described the time commitment as a factor for why practicing teaching did not use inquiry. During their final reflections, pre-service teachers realized that inquiry requires more effort initially to prepare the lesson but once the teacher had sparked students' interests and helped them get started, the students were the ones asking many of the questions and carrying out the investigations.

Another misconception I identified in some of their reflections is the notion that the scientific method does not include inquiry. One student described inquiry as, "I am learning a new approach to teaching science outside of the scientific method." From my explanation of inquiry, I had somewhere given the impression that inquiry was incongruous to the scientific method when, in fact, the scientific method can be a tool used to carry out inquiry investigations (Reiff et. al, submitted).

Implications

This study documents how pre-service students can improve their understanding of inquiry, but stops short of determining whether understanding becomes future practice for these future teachers. Hewson, Tabachnick, Zeichner, & Lemberger (1999) discuss that in order for a conceptual change to occur, an extended period of time is needed for students to make sense of their experiences. Even if standards mandate inquiry-based programs, teachers cannot be expected to change their beliefs or practices overnight.

A single science methods course that emphasizes inquiry is insufficient to make a lasting impact on teaching practices. Although classroom teachers as well as faculty members may recognize the importance of teaching inquiry, they may not know how to make such changes. Teachers at all levels should be supported while making the transition from more traditional methods to inquiry-based methods. Marilyn Zaretsky (quoted in Staten, 1998, p. 1) ascertains, "What we want from our students, we must give to our teachers first." As educators, we have a responsibility to prepare future teachers to teach in accordance to the standards. The problem remains on how to expect pre-service teachers to implement a method or concept that is not clearly defined.

Some teachers may think they are teaching inquiry when they really are not. This is a problem that will continue to exist as long as inquiry is loosely defined. Hardy (1998) considers that inquiry is the only teaching strategy that gives students a chance to explore the processes of science. Hardy further notes that under the "banner of inquiry, a lot of teachers do a lot of traditional teaching" (p. 28). This statement stresses the importance of asking teachers to construct their own definitions of inquiry then to look for examples of inquiry in their teaching.

Presenting inquiry through modeling or having pre-service teachers read about inquiry is not the same as a reflective process in which they move from defining inquiry to deriving a meaning for inquiry. Reflections are a way for pre-service teachers to figure out how they think and feel about inquiry, to identify instances of inquiry during their teaching, and to measure how much they have changed in their thinking. If I had assigned one reflection either at the beginning or the end of their teaching experience, pre-service teachers would not have had a reference point for how they initially felt about inquiry. This process helped them to see for themselves how much their definition of inquiry had expanded and had developed a deeper meaning.

Originally, I considered the reflections as a way to assess their understanding of inquiry but the reflections soon became a tool for pre-service teachers to see how far they had come in their thinking of inquiry. The reflections also provided me with evaluations of my presentation of inquiry to pre-service teachers. Some of the misconceptions that surfaced were ones I had not considered but ones that I will try to address in the future. I will also expect pre-service teachers to initially resist inquiry because of their lack of experience but I am more convinced now than ever the value of experiencing and reflecting on inquiry.

Future pre-service teachers can also benefit from reading the reflections of former pre-service teachers. They will be able to see how their peers articulate inquiry and some of the confusion and apprehension of teaching this unfamiliar method. Perhaps reading how others define inquiry can help future teachers see the process of understanding inquiry and how it works.

The title of this paper was inspired by one of my elementary science methods students who asked, "If inquiry is so great why isn't everyone doing it?" She had a valid point. Recently, schools of education are stressing the need to use inquiry-based teaching methods; yet, many of the teachers our students observed are not using these methods. In-service cooperating teachers rarely use inquiry-based methods in their classrooms nor do their college-level science instructors. Without good models that pre-service teachers can observe and experience, methods instructors alone cannot be expected to successfully inculcate students with these techniques. Inquiry cannot be learned from a textbook or from a single methods course. Pre-service teachers must be given time to assess the teaching methods they experienced in school, to evaluate additional teaching methodologies, to practice using a variety of teaching approaches, and to reflect on the effectiveness of each method. Inquiry has to make sense to teachers so they will use it because they want to not because the standards mandate inquiry teaching.

The following are some suggestions for teaching pre-service teachers inquiry:

1. Have a field experience in place for them to practice inquiry techniques.
2. Model inquiry practices. Show different levels of inquiry from a more structured approach to one that is more open ended (Colburn, 2000).
3. Expect students to question the effectiveness of inquiry.
4. Use reflections to identify misconceptions and to deepen their understanding of inquiry.
5. Discuss during class their inquiry teaching experiences.
6. Help students realize a wide variety of instructional methods. Compare inquiry to these methods. Inquiry does not have to be used all the time.

The National Science Foundation (1996) reports that "...few teachers, particularly those at the elementary level experience any college science teaching that stresses skills of inquiry and investigation, they simply never learn to use these methods of teaching" (NSTA Reports, p. 11). If teachers receive training that is traditional then they are more likely to continue the cycle of textbook oriented science. Forms of reflection such as how pre-service teachers define inquiry, how they incorporate inquiry into their teaching, and how their conception of scientific inquiry changes after teaching inquiry is essential to supporting pre-service teachers in their transition to inquiry-based teaching. Instances such as these, filled with real life experiences, provide a deeper understanding of how inquiry is incorporated into teaching practices and put into action.

Conclusion

This paper selected journal reflections from 48 pre-service elementary teachers who reflected on the meaning of scientific inquiry before, during, and after their field placement experiences. In the science education department, we were expecting students to teach inquiry yet many of their teachers in elementary and secondary schools did not use this method and neither did their college professors. Teacher educators cannot expect students to learn how to teach inquiry by having taken one methods course that discusses inquiry. Inquiry is not easily defined and, so, cannot be learned from a textbook.

Examining pre-service teachers' conceptions of inquiry has allowed me to identify misconceptions about inquiry. If teachers are expected to teach inquiry then it is important to develop a common conception of inquiry. Since inquiry has been loosely defined in many contexts, helping to define inquiry can be a pivotal step in actually asking teachers to teach a method with which educators are familiar.

The importance of revealing pre-service teachers' conceptions of inquiry provides valuable insight into how pre-service teachers make the transition from seeing a science lesson that is prescribed to a lesson where students and even the teacher develop a sense of wonderment. The nature of inquiry is active because in order to understand inquiry, one actually needs to *do* inquiry.

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SCIENCE DRAWINGS AS A TOOL FOR ANALYZING CONCEPTUAL UNDERSTANDING

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Children begin written communication through drawing before they learn to write. Our research focus has been on the extent to which student drawings may be a useful tool for understanding what students know, uncovering potential misconceptions, and making curricular decisions. In a previous study (McNair & Stein, 2001) young children and preservice teachers were asked to draw a plant and include plant parts, functions, and information about what plants need to grow in their drawings. Many of these preservice teachers would soon be teaching young students who would use drawings as a way to communicate ideas. It was believed that by having preservice teachers draw, they would not only experience this mode of communication with respect to thinking about the value and limitations of student drawings, but the drawings would also provide information about the preservice teachers' understandings and/or misconceptions about plants. The previous sample included children who ranged in age from four to eleven. For this study, a sample of twenty-four fifth graders and sixty-one high school biology students were asked to complete plant drawings. The drawings were coded and analyzed with respect to represented understandings about plant anatomy and plant requirements for growth. The results provided information about how student drawings can aid the teacher in making curriculum decisions and help students think about their own beliefs and areas of confusion.

Teachers of young students often ask their students to express their understandings and ideas by drawing pictures. The formalized use of drawings as tools for understanding student beliefs has been used by some researchers (see for example, Braund, 1996 or Tunnicliffe & Reiss, 2001), however, is not well documented in the literature. As students learn to write, there tends to be less and less emphasis on using drawings as a way for students to demonstrate understandings and communicate ideas. High stakes tests have also had an increased emphasis on student writing and, even when drawing is clearly the best method to communicate a specific idea or understanding, older students and adults do not often choose this method to communicate their ideas (Stein & Power, 1996). This may happen because of the emphasis on writing, over drawing, in the curriculum. Older students may lose some of the confidence they had when they were younger in being able to clearly express their beliefs through drawings. Elementary teachers of younger students are often expected to glean information and understanding from students' drawings, yet drawing may not be a tool with which they have had recent experience. As with younger students, drawing may help pre-service teachers think about their own understandings. Further, it may help pre-service teachers understand the strengths and limitations of using drawing to understand student beliefs.

The open-ended nature of most drawing exercises can both help and hinder the ability to use drawings as a way to ascertain student understandings. Through drawing, students are free to include and/or place emphasis on ideas that are interesting to them or central to their understandings. Pictures drawn by a student can reveal how he or she perceives an object, and the degree to which a student observes details and represents them. They can serve as a "window" to a student's conceptual knowledge. For example, a student's drawing of a plant is likely to not only reflect what he or she knows about the structure of a plant, but may provide information regarding their theories about plants, such as what they need to grow, or what they look like under the ground. Using student drawings as a tool for understanding beliefs is particularly useful when the student has not yet learned to read or write. Student drawings can also serve as a window to viewing the kinds of learning experiences students have had. For example, when a number of students draw stages of bean plant growth or specific reproductive parts of a flowering plant, it becomes clear that students have been involved in instructional experiences involving these topics. The open-endedness of the drawing process can also make it difficult to ascertain what students understand. For example, a student may not think about drawing and labeling the reproductive components of a flowering plant even though the student knows and understands them well. If this is the information that is sought, the instructions provided to students on what to draw would need to specifically state this. Similarly, students may not draw or label things like air, carbon, dioxide or gases because they are invisible rather than because the student does not understand that a particular gas may be relevant to plant growth. Or, younger children may not draw the roots of the plant under the ground level because they do not know how to represent this in a drawing, rather than because they do not know about the existence of plant roots.

When children decide what to draw, striking features such as shape, size or color, can become criterial in determining their mental models for various types of species (Tunnicliffe, 2001). Bell (1981) found that children did not consider trees as plants and that children aged 9-15 had a much narrower meaning of the word plant than did biologists.

When pre-service teachers draw to express their beliefs, the process can generate the same kind of deeper thinking as it does in younger students. When included as part of their curriculum, pre-service teachers can also examine the benefits, as well as the limitations, of using drawing as a tool for understanding student beliefs. Thinking about the details of an object during the drawing process is likely to motivate the learner to notice more specific information in subsequent observations. They may notice discrepancies in their own thinking about a concept and in the way they have either observed an object or phenomenon, or represented it. Drawings have personal relevance, and are helpful to the learner's process of figuring out how the world works.

According to Katz (1993), children in the Reggio Emilia schools in Italy use graphic languages, such as painting, drawing, constructing, collages and puppets to represents ideas and to document experiences. These representations allow children to further explore their understanding of concepts, as the process of drawing provokes questions and invites clarification. As a result, children reconstruct earlier concepts, and are able to revisit their representations in order to more completely understand an idea. Children can use drawings to problem-solve, or to re-think an idea. In this way, drawing is both a learning experience and an embedded assessment. Embedded assessments build upon teaching practice, rather than interrupting the process.

Understandings of Plants

During the elementary grades, children build understanding of biological concepts through direct, concrete experiences with living things, their life cycles, and their habitats (National Research Council, 1996). Research has shown that children and adults often develop understanding about their physical and natural world which are quite different to those presented by the scientific community (Osborne & Freyberg, 1985; Angus, 1981). For example, children often ascribe human characteristics, or anthropomorphic explanations, to organisms as they interpret the organism's attributes and functions with respect to their own experiences. As students gain a variety of experiences related to the characteristics of plants and animals, it is expected that their views will also change. However, even when students have a variety of concrete experiences, there are often some aspects of scientific phenomena that are so different than human experiences that the development of scientifically accepted ideas can be rare, and misconceptions can prevail.

Related to studies conducted by other researchers (Bannister, 1998; Arnheim, 1969; Dove, Everett, & Preece,1999; Rennie, & Jarvis, 1995), we have found that using students' annotated drawings of plants has helped us to understand their ideas about plants and what they need to grow. Annotated drawings have also provided a useful tool for discovering student misconceptions and planning for instruction that will help each student's conceptual development.

According to the National Science Education Standards (NRC, 1996), students in grades K-4 should understand that: plants have basic needs that include air, water, nutrients, and light; each plant has different structures that serve different functions in growth, survival, and reproduction; and that plants have life cycles that include being born, developing into adults, reproducing, and eventually dying. Students in grades 5-8 should understand: reproduction in plants; that plants and some micro-organisms are producers; and that sunlight is transferred by producers into chemical energy through photosynthesis (NRC, 1996, p. 157-158). High school students should understand the detailed nature of how plant cells use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment (NRC, 1996, p. 186).

Researchers have documented many commonly held misconceptions about plants. For example, many believe that plants obtain food through their roots (Barker, 1995). Roth (1985) developed a list of common misconceptions about plants and plant growth. They include:

- Plants can live and grow only in the light;
- Food for plants is either fertilizer/plant food, things plants need like raw materials such as

water, sun, fertilizer, shelter, or things plants take in or "eat" (raw materials such as water, fertilizer, sun);

- Plants get food from soil and water;
- Plants get food from many sources (as humans do);
- Anything that is taken into the body or that helps an organism live could be considered food.

In light of students' direct experiences with plants, many of these misconceptions seem to be reasonable assumptions in understanding the function of plant parts and what plants need to grow. It is through experiences teachers create to help students develop deeper understandings that students will be enabled to move beyond the misconceptions listed above.

Setting the Stage for Reflective Drawing

Two samples were used for this study: 24 fifth graders and 61 high school biology students. All students were from the same school district; a large, suburban district that is well regarded with respect to the science curriculum provided to students. Students in this district score above the state average on the statewide science assessments administered in 5th, 8th, and 11th grades. The drawing activity took place during the second semester of the school year. Students were instructed not to put their names on the drawings and that the drawings would not be used for classroom evaluation. Instruction on plants had not occurred prior to the drawing activity. The directions were:

> Think about what you know about plants; what they look like, and how they grow. Draw a plant. Draw (or label) as many things about the plant as you remember. In your drawing include what the plant needs to grow. Write down words, or label your drawing, to help us understand what you drew.

After the drawings were collected, they were coded with respect to inclusion of specific plant parts and information about what plants need to grow. The coding categories were previously established (McNair & Stein, 2000) by detailing the components drawn in a large sample of drawings and looking for commonalities. In addition to establishing categories for items that were commonly drawn or labeled, categories were also established for items that are important to understanding plants as established by the national standards. For example, it is very important for students to understand that air, or gases such as carbon dioxide and oxygen, are important to plant growth. So, although air or gases are not commonly labeled in student drawn pictures, these categories are included in the coding process. The coding categories were: sun/light, rain/water, soil/nutrients, air, carbon dioxide, photosynthesis, roots, stems, leaves, flower, petals, pistil, and stamen. Any other unique images or labels were written separately. When a drawing included both an image and label, it was coded with a "2", if it included either an image or a label, it was coded with a "1", and if an item was not present it had a value of zero. After coding categories and procedures were established, a small sample of 5 drawings were coded independently by two researchers. The results of the coding were compared and discussed. Only minor discrepancies occurred. Five additional drawings were independently coded and compared. The results were exactly the same and the coding process appeared to be reliable. The remaining drawings were coded independently by the two researchers and, once again, the results were compared. The few discrepancies that emerged were due to human error rather than the coding process. For the purposes of determining whether a student indicated a specific item within a drawing for this analysis, items coded as "2" or "1" were counted as being present in the drawing.

Learning from Student's Drawings

Using the formal coding process described above, each drawing was analyzed for the information it provided on: (a) what plants require to grow and; (b) structure of a plant that students were able identify. The results provided very interesting information about students' conceptions of plants and the types of information they chose to represent in their drawings.

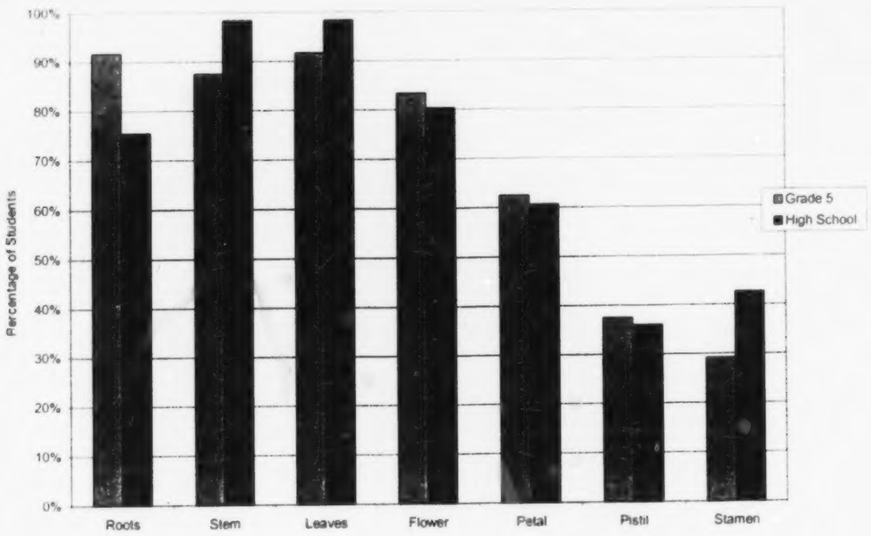

Figure 1. Student Representation of Plant Anatomy

Figure 1 shows how students in both samples represented plant anatomy. Similar to results found by other researchers, most students drew flowering plants with 83.3% of grade 5 students (*n* = 24) and 80.3% of the high school students (*n* = 61) drawing these types of plants. Only 6 drawings from either sample were of trees, similar to the results found by Bell (1981). Also similar to results found by others (Tunnicliffe, 2001), students drew and labeled plant parts that

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were large or colorful. For example, 62.5 % of the fifth grade sample and 60.6% of the high school sample labeled petals on their drawings. Most surprising about these results is that there appeared to be little difference between the fifth grade students and the high school students, particularly with respect to specific items that would indicate a more detailed knowledge of plant anatomy. For example, 37.5 % of the fifth grade students labeled "pistil" on their drawings and only 36.0% of high school students did so, while 29.2 % of fifth grade students and 42.6 % of high school students labeled "stamen" on their drawings.

When analyzing the drawings with respect to what students believed plants need to grow, we found results that verified those found in the previous study with young children and preservice teachers (McNair & Stein, 2001). That is, students represented that plants need sunlight, water, and nutrients with more than 87 % of the students representing each of those items in their drawings (see Figure 2). Surprisingly, the fifth grade students were more apt to include each of these items in their drawings when compared to the high school sample. When comparing the drawings of the fifth grade students to those of the high school students, a noticeable difference occurred with respect to representing air, carbon dioxide, and photosynthesis in their drawings. Air or carbon dioxide was not represented by any fifth grade students in their drawings, while for the high school students 6.5 % represented air and 18.0% represented carbon dioxide in their drawings. One 5th grade student represented the process of photosynthesis, while 14.8 % of the high school students represented this process. While these results show some clear differences between the high school and elementary students, the low percentage of representations of air, carbon dioxide, and photosynthesis by the high school students is discouraging.

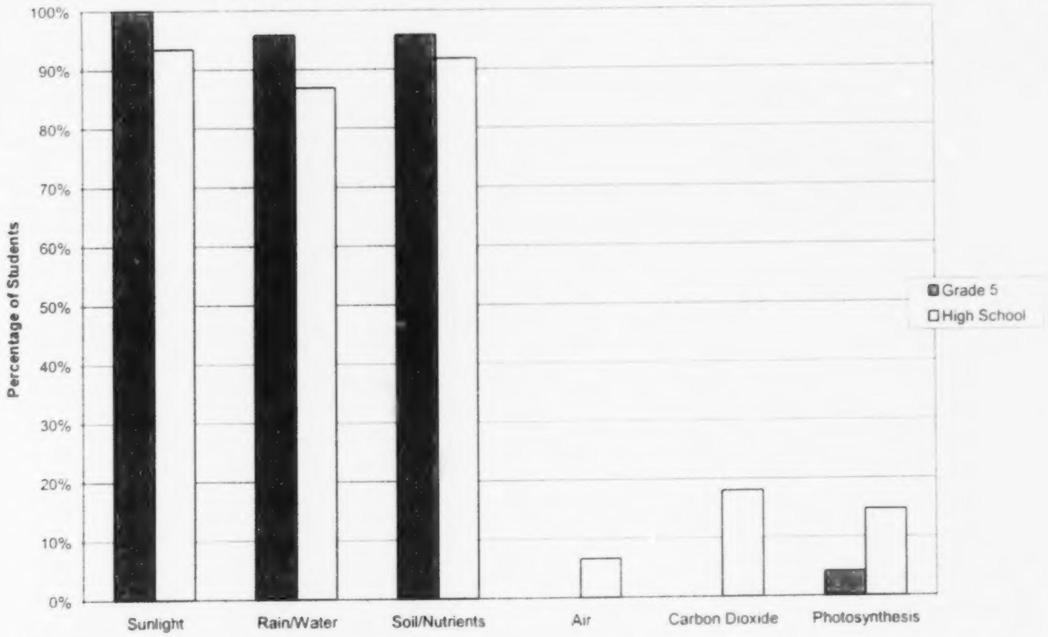

Figure 2. Comparison of Representation of Plant Growth Requirements

Finally, the representations of plant growth requirements were compared to the representations of these items by preservice teachers found in an earlier study (McNair & Stein, 2001). In the pre-service drawings, it was interesting to note that 28.6 % either labeled, indicated, or wrote "photosynthesis", but less than 10% included the presence of air or other gases in their drawings (see Figure 3). The preservice sample exhibited a higher representation of photosynthesis than the high school sample, but exhibited lower representation of air or carbon dioxide. In the other coding categories, representation of sunlight, water, and nutrients was similar to the two samples in this study.

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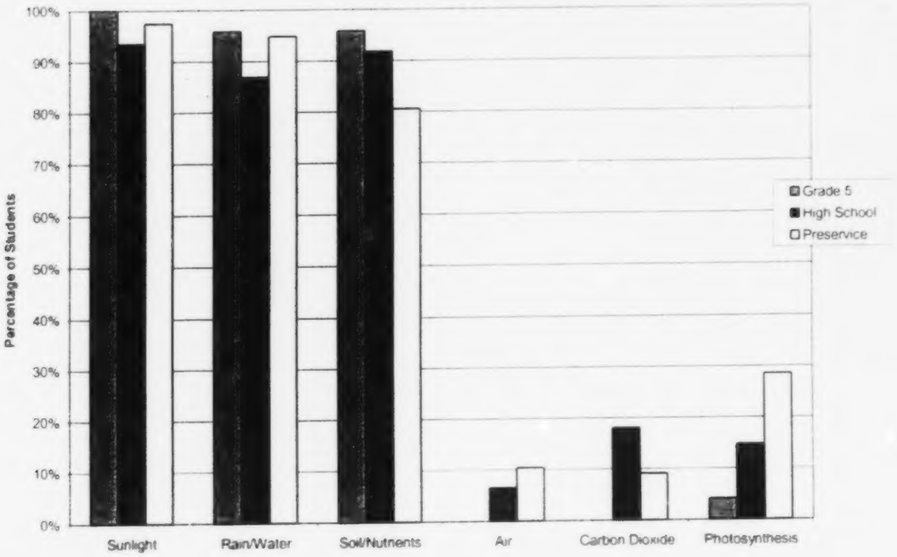

Figure 3. Comparison of Representation of Plant Growth Requirements

Conclusion

The drawings, even before undergoing a formal coding process, provided a great deal of information about student's understandings. From the drawings it became clear that most students had some knowledge of general plant anatomy and what plants need to grow. The drawings showed that they often had specific experiences and information that they brought to the learning situation. For example, it was evident that identifying reproductive parts of a plant must be a part of the science curriculum not only for the high school students, but also for the fifth grade students in this study. Some drawings also provided information about specific misconceptions held by students. For example, one 5th grade student wrote:

> Decomposers like worms and fungi fertelize nutriance into the soil so plants eat it. Worms also shift soil for roots of a plant to get through. (Case #106)

Another high school student wrote:

> The plant goes through photosynthesis and gets chlorophil
> l and the chlorophil makes the plant green. (Case # 7)

These results also support the results found by other researchers: that students tend to draw flowering plants most often and that they focus on characteristics involving, color, shape, or size. The drawings also provided some information about the curriculum and the instruction with which students had been involved. When students included scientific terms in their drawings such as "pistil", "stamen", "photosynthesis", it is probable that this was information provided through classroom instruction. Thus, it is also troublesome when only a small percentage of students represent information that may have been an integral component of the curriculum. One might expect that, with experiencing approximately five years more science instruction, the high school students' representations of understanding and knowledge about plants might be significantly different from those of the fifth grade sample. This was not the case. This was further supported by the similarities in representations when comparing the high school and preservice samples. Although there is a greater representation by older students of the ideas of photosynthesis and specific gases being an important component of plant needs, only a small percentage of students represented those items.

Our experience with using students' drawings as a "window" to understanding beliefs about plants has provided us with some important insights. As a pre-assessment tool, drawings not only provide the teacher with information about student beliefs before instruction begins, but can also provide a mechanism for providing the teacher with indications about the curriculum students have experienced, as well as helping students grapple with their own ideas and questions. This strategy may help to engage students in wanting to know more about the particular science topic to be taught.

As a tool for developing curriculum and sequencing instruction, drawings can help provide insight into what activities will best serve students' learning needs. In this sample, although students seemed to have experienced instruction on photosynthesis, the understanding that gases were important to plant growth was not evident in their drawings. The teacher would know that students need a better understanding of the role that air has in plant processes and can plan instruction accordingly.

Finally, our results have provided us with information that helps to show the development of ideas over time. It is clear that many pre-service teachers do not understand plant growth well. While they identify sunlight, water, and soil/nutrients as plant needs, most do not go beyond that level. How then, will these teachers be able to support students' building of their understandings of more advanced concepts? From the results found in this study, it is clear that high school and fifth grade students also do not understand these processes well. The teacher has a direct and important impact on the development of scientific concepts and must understand scientific phenomena at least one level beyond where their students need to go. The student representations in this study indicated that there was little difference in the understandings of high school students or preservice teachers when compared to the understandings of upper elementary students. If teachers are enacting the curriculum that is designed to address these topics, then it is clear that students are not developing a deep understanding of the concepts involved.

We believe that drawings are often an under-utilized tool in science classrooms. Drawings can provide valuable information to the teaching and learning process and, more importantly, they provide an open-ended means for creative expression that is difficult to achieve with other assessment strategies.

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BUILDING CONFIDENCE IN PRESERVICE ELEMENTARY SCIENCE TEACHERS

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Nationally, each year, 40 percent of new graduates from traditional teacher education programs do not take up teaching positions (Darling-Hammond, 2000). There are a number of reasons for this, but, at the elementary level, one aspect is a lack of confidence to teach in unfamiliar subject areas, particularly science and mathematics (Silvertsen, 1993). Hawkins (1990) suggested that science teaching is caught up in a "loop in history" in which new teachers tend to repeat the way they were taught science. Elementary preservice teachers frequently comment that their strongest memories of elementary and middle school science were textbook driven lessons, and answering questions at the end of chapters. In general, most elementary preservice teachers report that they have an inadequate conceptual understanding of science and therefore are not confident to teach it (Weiss, 1994).

While other researchers have examined various factors (Jarrett, 1999; Settlage; 2000; Tosun, 2000; Wingfield, Freeman, & Ramsey, 2000) that contribute to science teaching confidence, we are foregrounding conceptual understanding as the foundation that must be in place to nurture teaching confidence. We have adopted the motto of "success breeds success" to guide our teaching and research. We believe that if students have personal success in learning science then they will be more confident to teach it.

This study examined learning activities that resulted in conceptual understanding that led to growth in teaching confidence in two sections of a preservice elementary science methods course taught by different professors (the two authors) on the main campus and a satellite campus of a large university in south Florida. We believe there is a difference in the depth and meaning ascribed to a learning experience if it is learned using social constructivist practices. Thus, having experienced learning from a social constructivist perspective, teacher education students will then be more likely to teach from that perspective. It is important that they be provided with the time and opportunity to experience success at constructing their own conceptual understanding.

Our research and teaching has been informed by the literature on self-efficacy (teaching confidence) and constructivist learning theory.

Theoretical Framework

Self-Efficacy (Teaching Confidence)

The connection of attitudes and beliefs to practice can be captured by the psychological construct of self-efficacy. In this study, the term "teaching confidence" is substituted for "self-efficacy expectation" since it is the common term students and teachers use to express their feelings of self-efficacy. We talk about *feeling* confident to do something in everyday life. Though the word "feeling" is used, confidence is much more than a feeling. It is an attitude, based on a belief that a person has the ability to get the job done, answer the right question, or come up with the best plan. Thus, teachers who have high teaching confidence will perceive that they can teach effectively. Albert Bandura's theory of social learning (Bandura, 1977, 2000) provides a useful framework to explain how this works from a cognitive science perspective. Simply put, Bandura's theory posits that we are motivated to perform an action if we believe that the action will have a favorable result (outcome expectation) and we are confident that we can perform that action successfully (self-efficacy expectation). Self-efficacy has been studied from many perspectives (Tschannen-Moran et al., 1998). However, within science education, Bandura's model has been widely taken up due to its utility in research on science teaching and teacher education.

Based on their conviction that preservice teachers' beliefs about science and science teaching and learning were a limiting factor to their development as teachers in elementary preservice methods courses, Enochs and Riggs (1990) developed a research program based on Bandura's self-efficacy theory. An important contribution was the development of a valid and reliable instrument (the Science Teaching Efficacy Belief Instrument, STEBI-B) that could be easily administered to measure the two components in this theory. They urged that the early detection of low self-efficacy in elementary science teaching was critical to any teacher preparation program. Several researchers have heeded this advice and used the STEBI-B to explore issues of self-efficacy in preservice elementary teachers (e.g., Settlage (2000) examined learning cycles and self-efficacy; Schoon and Boone, (1998) studied alternative conceptions and self-efficacy; and Scharmann and Hampton (1995) examined self-efficacy in relation to cooperative learning). In our study, we highlight the relation of teaching confidence (self-efficacy) to conceptual understanding, particularly from a constructivist perspective.

Constructivist Learning Theory

This study is framed in a constructivist approach to teaching and learning science. From our perspective, knowledge must be taken in and made one's own as the result of a process of construction in which what is already known and believed interacts with the new concepts being learned. Without this interaction, new understandings are not deeply established and therefore do not meet the test of time. What the learner already knows is the most important factor affecting learning. When it comes to the teaching of science, learners' prior understandings are frequently discounted or neglected and learning paths are not well designed to lead to new science understanding for the student (Duit & Treagust, 1998). Teachers with a constructivist orientation believe that the learning opportunities that they plan are the mediating processes that help students move from their current understanding to new understanding.

At the core of constructivism lies the idea that an individual's own conceptions guide their understanding (Tobin, 1993; Tobin & Tippins, 1993). In the 1980's, in what Duit and Treagust (1998) call 'mainstream constructivism' the social aspect of constructivism was not widely acknowledged and instead the emphasis was on the individual's own constructions. In more recent years, social constructivism and the importance of the social aspect of constructing knowledge has been recognized and taken hold (Duit & Treagust,1998; Roth, 1995). The appropriation of the social aspect of knowledge construction has made the original constructivist view more inclusive because it now encompasses both the individual perspective and the social perspective.

In order for the construction process to take place, there must be adequate time and resources provided in the learning setting. This means that students must experience science events, interact with materials and each other and the teacher regarding these experiences. All of this occurs within a social setting, and is affected by the social interactions within the setting (Tobin et al., 1994). Later students reflect on what they have learned and more discussion and additional events may be necessary and important components to constructing deeper conceptual understanding. Further, we believe that the opportunity to construct conceptual understanding leads to healthy levels of confidence in preservice teachers and provides a firm foundation from which to teach. We recognize that pedagogical content knowledge (Shulman, 1987), which we attempt to model through our practices with preservice teachers, and classroom teaching experience are also necessary to be successful, but a firm foundation of conceptual understanding is the starting point.

Methodology

Design

The study employed a mixed method design (Frechtling & Sharp, 1997), involving both quantitative and qualitative research methodologies. Triangulation of findings from different data sources was employed to establish a measure of validity and confirmability (Guba & Lincoln, 1989).

Participants

Participants (*N*=49) in this study were two classes enrolled in the elementary science methods course offered at a large urban university in south Florida. The 6-week, summer course was offered on the main campus (*N*=26) and a satellite campus 35 miles away (*N*=23), taught by two different professors.

Instruments

Changes in students' science conceptual understanding were measured by administering a pre/post conceptual understanding test. Enochs and Riggs' Science Teaching Efficacy Belief Instrument, STEBI-B (Enochs & Riggs, 1990) was administered to measure changes in students' attitudes to science and teaching science were measured by administering a pre/post attitude survey. Students kept reflective journals throughout the semester. Exit interviews with a sample of students (N=10) were conducted at the end of the semester. Notes were taken during the interviews.

Analysis

The STEBI-B and conceptual understanding test results were analyzed by a comparison of means between matched items on the pre and post survey. Journal entries were submitted to content analysis. This involved both researchers independently searching student journal entries and critiques for evidence relating directly to our thesis that conceptual understanding is the foundation for development of teaching confidence.

Context of the Study: The Methods Courses

Teaching Philosophy

Both professors had a shared philosophy, which guided the research and teaching. We planned our instruction so that students would have a firsthand experience of constructing their own understanding of science. Thus, our philosophy was to model constructivism as a referent for teaching science (Tobin & Tippins, 1993).

Course Curriculum

The curriculum was designed for preservice elementary teachers to focus on core concepts and principles in science. Instructional strategies and curriculum design features that allow students to construct their understanding were modeled. The science content served as the context for hands-on activities and discussion, demonstrations, discrepant events, and cooperative group work, all strategies that we hoped students would employ when teaching science. National Science Education Standards (NRC, 1996) were reflected in the constructivist orientation of the course with an eye for depth over breadth and a teaching perspective of 'less is more'.

Instructional Approach

The methods course utilized an inductive instructional approach that engaged students in a cycle of learning focused on understanding, that began with reflection and hands on experiences related to a concept, followed by discussion about the concept, and concluded with further extension of the concept via more hands-on experiences and reflection in dialog journals. Students read selected materials that focused on a constructivist approach to teaching and learning science (Brooks & Brooks, 1997). A constructivist instructional method or strategy was specifically examined and students taught a lesson to the class utilizing The Learning Cycle (Abraham, 1998).

Results

Pre-Post Science Conceptual Understanding Test Results

Both classes made significant pre-post test result gains in conceptual understanding in the physical science areas highlighted in the course. For the two classes taken together as one group (N=49) the gain was also significant (t=16.626, p=.001).

With the emphasis placed on learning science content, it was hoped that there would be strong gains in conceptual understanding. The quantitative results are supported by student comments in their journals. A few student journal responses are given to illustrate how students expressed their awareness of changes in their conceptual understanding.

> Vicki: I learned more about matter in class today than I had in elementary or middle school. I always had difficulty comprehending how gas took up space. Today I finally 'saw' that it does.
>
> Nancy: I feel like I am learning what I should have learned in elementary and middle school. I look forward to the class each day.

Pre-Post STEBI-B Results

Based on Bandura's two-component model, the STEBI-B is composed of two scales, measuring teaching confidence (self-efficacy) and outcome expectancy. An independent 2-tailed t-test, revealed no significant differences between the two methods classes on either scale. However, for the 49 students in both classes taken together, a paired samples t-test revealed that there was a significant gain in teaching confidence (t = 8.381, p=0.001), and a significant gain for outcome expectancy (t = 3.060, p = 0.002).

These quantitative results are supported by numerous student testimonies of their increasing confidence during the course. Typical comments are given below. We also asked students periodically to rate their confidence levels on a scale of 1-5 {1 being the lowest and 5 being the highest} for learning science and then teaching science. When available, we have indicated these confidence level ratings.

> Nancy: I am very happy I decided to take science before my student teaching, because my confidence level is going up. I felt that I couldn't be a good teacher because I wasn't comfortable with science. I realize I do not have to know everything but need a basic knowledge of the content. I can research topics and be comfortable teaching about that. (Nancy's confidence level for teaching as she reported in her journal went from a 1 to a 3 in the first few weeks of the course.)
>
> Barbie: I have really enjoyed this course. I wouldn't say that I'm completely confident about teaching science, but I am definitely more comfortable than I was before the course. (Barbie's reported confidence level for teaching science went from a 2 the first week of the course to a 4 by the end of the course when she wrote the above statement.)

Assertion 1. *Hands-on activities and discussion elucidated particular scientific concepts that led to conceptual understanding.*

Two students expressed the benefits of doing hands-on activities in a particularly reflective manner in a focus group discussion. A short conversation between Penny and Sally illustrates this:

> Penny: I would not have understood many of the concepts without doing the activities or the demonstrations. I needed to do these and see these to really understand. I don't have a good science background.
>
> Sally: The hands-on activities and demonstrations made the concepts become clear. I was just thinking about this as we reviewed for the test on Monday. In response to questions (asked by students), you responded verbally, and with drawings on the chalkboard, and I could think back to what was referred to and visualize what had happened during an activity related to a concept and related to the question. It passed before me in my mind and I

> could 'see' things happening as I listened to your responses and to questions. Referencing visually to things we have done helped me so much to understand and remember. I also thought how just the talk and drawing would not have done it for me.
>
> Penny: Yes, I have those things to grab onto and to use as references for concepts that I initially found confusing. I am not so sure I would really have understood some of the ideas if we hadn't done the 'labs' in class. I often went home and tried these things again with my daughter.
>
> Sally: I could see the convection occurring, the colored hot water rising and the cold clear water falling and the two waters mixing so quickly, and then that when the bottles were reversed, the setup was reversed, how the two just didn't mix at all, they just sat there because the less dense fluid was on the top and the more dense fluid was on the bottom. That really helped me. I can see the power of hands-on.... but you have to think about this as well to make it meaningful in the long run. Discussion helps too. I don't really understand some of the most basic science concepts. I am looking forward to the other experiments we will be doing so that I will be more confident teaching science.

Sally wrote later in her journal, "If my past science teachers would have done more hands-on activities, maybe I would have been a scientist of some sort, who knows!" Sally's comments are particularly striking considering her lack of confidence at the beginning of the course, both for learning science and teaching science. Students repeatedly expressed how important hands-on activities were in helping them construct their science conceptual understanding, and both classes highlighted the use of hands on science activities.

The critical importance in terms of gaining understanding from doing hands-on activities as expressed by our preservice teachers are in line with the National Science Education Standards NRC, 1996). In the opening overview of the Standards it is stated, "The Standards rest on the premise that science is an active process. Learning science is something that student do, not something that is done to them. Hands-on activities, while essential, are not enough. Students must have "minds-on" experience as well (p. 2)". This warns educators, that it is important to engage students in hands-on activities, but these activities must be closely linked to prior and subsequent conceptual learning. That is, an effective science curriculum is hands-on, and minds-on as opposed to hands-on alone or no hands-on at all. This leads into our second assertion.

Assertion 2. Learning in a constructivist environment allows the preservice teacher to reflect on his or her own learning and connect the experience to teaching.

All students expressed their ideas both verbally and in writing about their understanding of constructivism based on reading assignments and class discussions. Typical examples of such expressions from their critiques and journals follow.

> Maria: Constructivist teachers inquire about students' understanding of concepts before sharing their own understanding of those same concepts. This is a crucial part of teaching because teachers have the influence to completely change a student's perspective. Students need to be given the opportunity to express their own ideas even with misconceptions before the teacher's input changes those thoughts.
>
> Chrissy: I really hope that I can be like some of the teachers we have read about. I really want what is best for my students. Being a constructivist teacher seems to be the best. Giving students time to think about a question before they answer it is important. I felt I never had time to answer questions when I was in school.
>
> Julie: I am really starting to enjoy the idea of the hands-on, minds-on science approach. There has always been talk of the hands on approach because it made learning concrete for students because it was usually something the students could touch and see. When you use the minds on approach the students are challenged to think for themselves. They are not punished for their ideas, meaning they are not told that they are wrong. They must prove their ideas and theories. This also makes them accountable for their work.

Conclusions

Students indicated that they understand what they are learning in science. Their perceptions are congruent with the increase evidenced in their understanding of science concepts as shown on the science content Posttest conceptual understanding test. We feel these comments are indicative of how students react to learning science in the constructivist environment compared to more traditional learning in earlier school experiences. From our conversations with students, we see this as not so much learning a concept for the first time, as some of them express it, but becoming more aware of how they are perceiving and understanding a particular concept. We see these student reactions as appreciating a classroom environment based on promoting meaningful learning (Novak, 1998). It is interesting to note that even students who have had many science courses, and reported being successful in earlier science classes found benefit in seeing and experiencing hands-on-minds-on science. The constructivist science environment appears to aid conceptual understanding at a deeper more meaningful level, and affect beliefs that they will more likely retain the ideas over time. We believe that the success our students achieved strongly influenced their perceptions that they will be more successful in teaching science. If students feel confident to teach science, they will be more likely to do so and be enthusiastic in their efforts.

We believe that the answer to providing better science understanding for preservice teachers is not met sufficiently by just taking more science courses in the College of Science. Somewhere between subject content knowledge and pedagogical content knowledge lies the knowledge base we are tying to instill in preservice teachers – this knowledge base is a special type of subject matter knowledge we call conceptual understanding constructed in a constructivist learning environment. This is important for two reasons: (a) it is understanding that is long lasting – that belongs to the learner and (b) because students experience learning constructively, they will be inclined to teach constructively and break the "loop in history" which Hawkins discussed.

What would be most beneficial for preservice teachers would be to provide an opportunity to spend a period of time in a school setting either during the semester they take the science methods or directly after. During the time in the school they could teach a set of lessons that they designed and felt comfortable with to children under the guidance of a teacher with a constructivist perspective. This would be best to do when their confidence and recent exposure to constructivist teaching is at a high. As our program is now structured, this occurs only occasionally. Most frequently, students must wait a semester or longer for the opportunity to teach a series of science lessons. A comparison of students who have such opportunities with students from our classes who do not would be an interesting study.

Preservice elementary teachers can be exposed to ways of thinking and practicing science education in a methods course that can have a strong effect upon their beliefs that form the foundation for their future practice. Further, the early training in reflecting upon their teaching is crucial to lifelong professional development in their teaching careers. Strengthening of healthy beliefs about teaching and learning in preservice teachers is an important educational concern in the new millennium. Early examination of preservice teachers' confidence (self-efficacy) in learning and teaching science is crucial to ensuring that new teachers will succeed in their practice.

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CHEMISTRY STUDENTS' CHALLENGES IN USING MBL'S IN SCIENCE LABORATORIES

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Introduction and Literature Review

Increasingly, many educators have reported that new technologies can enhance students' performance and motivation. As one example, Hodson (1996) suggests several reasons for using technology in laboratory settings:

> Motivating students by stimulating interest and enjoyment; teaching laboratory skills; assisting concept acquisition and development; developing an understanding of scientific inquiry and developing expertise in conducting inquiries; inculcating the so-called scientific attitudes; encouraging social skill development. (p. 756)

Above statement by Hodson above indicates the importance of technology in preparing students for lifelong learning. In this sense, incorporating Microcomputer Based Laboratories (MBLs) into instruction have potential to foster students' learning of the scientific content and help them be better prepared for the workplace where technical and social skills are very important.

As new technologies such as MBLs become available to education, researchers, educators and experts in science teaching seek ways to effectively incorporate the new technology into curriculum. In this regard, many researchers have conducted studies to determine the impact of real-time data collection on understanding the scientific content. As an example, Nakhleh &Krajick (1994) focused on the influence of MBLs on students' content knowledge. They concluded that students using MBLs had increased their levels of understanding about acids, bases and pH above students using the more traditional laboratory approaches (using pH meters or indicators). In a separate study, students using MBLs required less time to understand the relationships between the content, the theory and the actual data collected, when compared to students using traditional laboratory techniques (Friedler, Nachmias & Linn, 1990; Settlage, 1995). In a study with third grade students, Settlage and his colleagues found that MBLs enhanced the children's science learning specifically by increasing the ways and forms of doing scientific inquiry. . In another study, Mokros & Tinker (1987) indicated that MBLs could help students in gathering and analyzing data, generating questions and sharing their opinions and results. In the same study, they found that students are better at interpreting the findings of their experiments when they use real –time data collection than when they construct their own graphs.

Also, many science educators(e.g., Linn & Hsi, 2000) support the idea that MBLs provide with a strong medium for the discovery and exploration of scientific knowledge. Because with MBLs, data collection and the graphic representation of data can be handled in almost no time, thus allowing students more time to focus more on the interpretation of data (Rogers, 1995).

Furthermore, Nakhleh & Krajick (1994) reported that some MBL-related activities can have positive impacts on students' concept mapping skills. In the same study, students using MBLs had more unrelated items in their concept maps. Glasersfeld (1993) suggests that these unrelated items or links should be considered the products of successful thinking which, in most cases, is more important than "correct answers". This so-called "sophisticated level" of involvement with technology leads to "sophisticated levels" of information processing that involves reconstructions and constructions of meaning.

Reviewing the literature, McRobbie & Thomas (2000) summarized the ways that science students use of MBLs as to:

> (a) explore and understand workplace applications of science (b) develop skills of investigation, reflection, and analysis (c) generate and refine conceptual change (d)find solutions to problems, and (e) to pose questions for further. (p. 1)

They further reported that by using MBLs in their laboratory activities science teachers could provide collaborative and authentic learning opportunities for their students. In another study with third grade students, Settlage (1995) found that MBLs enhanced the children's science learning specifically by increasing the ways and forms of doing scientific inquiry.

More schools incorporate MBLs into their science laboratories in each year (MacKenzie, 1988; McRobbie & Thomas, 1998) as MBLs have the potential for positively affecting students' laboratory experiences in science classes by providing them with an opportunity of gathering accurate data that can be displayed and analyzed in real-time (Lapp & Cyrus, 2000; Linn, 1998; Nakhleh & Krajcik, 1993; Pena & Alessi, 1999;). Also, it is believed among educational stakeholders that adopting MBLs for use in school science curricular activities may alter the traditional ways of doing experiments by students and teachers (McRobbie & Thomas, 1998; Pena & Alessi, 1999; Thornton & Sokoloff, 1990).

As seen above many studies report the gains as a result of MBL usage in science laboratories however research so far does not provide compelling evidence that usage of MBL technology necessarily increases the learning outcomes (Lazarowitz & Tamir, 1994; Mcrobbie & Thomas, 1998). Although there are many studies conducted on MBL usage in educational settings, very few have directly investigated MBL usage in science laboratories from the students' perspectives. For successful implementation of MBLs into schools, McRobbie & Thomas (1998) strongly suggest that educators should take into account the teachers' and students' beliefs, concerns and views as these beliefs and concerns greatly influence teaching and learning. In this regard it is my hope that understanding students' concerns about this technology will in part help us identify the obstacles to science learning by using such technologies.

Thus, reviewing the early and recent literature compelled me to think about the appropriateness of using MBLs in the laboratories. I believe understanding students challenges from their perspective would provide important data as to understand their appropriateness in high school chemistry laboratories. Identifying students' concerns about this technology will in part help educators identify the obstacles to science learning by using such technologies. Also, understanding what MBLs are good for from student perspective would enhance a science teacher's ability to better incorporate MBLs into a science laboratory. Students' concerns and views about MBLs would provide valuable feedback for teachers as to finding effective ways of using this type of technologies.

Research Questions

In this study I sought answers to the following research questions:

1. What advantages and challenges do students encounter during MBL activities?
2. What are the views of high school chemistry students regarding the use of MBLs as a learning tool?

Methodology

The nature of this study made qualitative techniques that focused on interpretative inquiry appropriate. In this paper, I used the term interpretive inquiry interchangeably with the term constructivist or naturalistic inquiry (Guba & Lincoln, 1989). Interpretive research methods can be useful for examination of "what is happening" in a particular social setting, such as a classroom. Interpretivism tries to describe meaning attached to the situation and look for the patterns of meaning by guidance of a relativist philosophy (Guba & Lincoln, 1989; Creswell, 1994; Stake, 1995).

Guba & Lincoln describes an interpretive research as being a hermeneutic process. The purpose of hermeneutic process is to expose the constructions of the variety of concerned parties, open each to critique in the terms of other constructions, and provide the opportunity for revised or entirely new constructions to emerge. In this study, I completed hermeneutic circle (Guba & Lincoln, 1989) process by re-structuring the interviews and developing a more sophisticated meaning through my research.

The study reported here is a interpretive case study which relies on interviewing and observing . The nature of the questions asked in this study made qualitative techniques that focused on interpretative inquiry appropriate. In this paper I tried to describe meaning attached to the situation and looked for the patterns of meaning by guidance of a relativist philosophy (Creswell, 1994; Guba & Lincoln, 1989; Stake, 1995). In this study the researcher sought to generate an understanding of the multiple perspectives coexisted amongst the students (Creswell, 1994).

Participants

Thirty-three students from two high school level AP Chemistry II classes and their teacher participated in this study. There were 15 students in the first section (Fourth period) and 18 in the second (Fifth period). Eight groups of students (seven pairs and one alone in the fourth period and six pairs and two groups of three in the fifth period) were engaged in the MBL activity. The students involved in this study were 11th and 12th grade students.

Most of the students involved in this study were already familiar with MBLs. They had used MBLs for collecting and analyzing data in their earlier science laboratories. However, only nine students did not have previous experience with MBLs. Ali, Durmus (pseudonyms) from the fourth period, and Emin and Yasemin (pseudonyms) from the fifth period were selected as the focus group students for more intense study than others. These focus groups were selected to be typical of others in the class and to comprise students who were cooperative. Students were provided with enough MBL stations to work in groups of two. It was assumed that students would work cooperatively in their investigation.

MBL Activity

Students performed an experiment about solubility of Vitamin C in orange juice using both pH and temperature sensors. For this activity, I prepared the experiment worksheet and named the document "MBL Activity" (Appendix B). Worksheets were reviewed by the teacher before the students performed the activity in the lab.

In the MBL Activity, students were asked to find the relationship between the temperature changes and the solubility of acids. Students used orange juice as the main material of the activity rather than using other acids or acidic solutions. The MBL system used in this study was composed of a Texas Instruments (TI) 83 plus calculator, a Vernier interface and probes. For the purpose of the MBL activity, students used the pH and the temperature probes.

Data Sources

In order to elicit the students' views and perceptions I designed a questionnaire and a semi-structured interview protocol with a number of open-ended and some close-ended questions.

Questionnaire

In the "MBL Activity Questionnaire" (MBLAQ), students were asked about their experiences of using the MBLs. Most of the questions were of an open-ended nature, in which I asked the students' perceptions of MBLs. Questions in the MBL Activity Questionnaires included:

(1) What impact, if any, did this MBL experience have on your engagement into the activity?

(2) In your experience, what are the advantages and the disadvantages of using the MBL?

The purpose of using MBLAQ was to generate one source of empirical evidence regarding the general views and perceptions of each student who performed the MBL Activity. Thus, I used MBLAQs as a central source of data in this investigation to better understand the overall perceptions of the students. Thirty-three questionnaires, fifteen in the forth period and eighteen in the fifth period, given to the students a few minutes before the class ended. Twenty-three of the questionnaires (ten in the fourth period, thirteen in the fourth period classes) were returned

In the MBL Activity Questionnaire, I asked the students to compare strengths and weaknesses of using traditional lab equipments and MBLs. They were asked about their opinions on the impact of using MBLs regarding their engagement into the activity. Students were also asked to elaborate on the successes and challenges they encountered with the use of MBLs during the experimentation. The questionnaire contained eight open-ended questions about students' perceptions of using MBLs. The patterns and themes that emerged from students' responses to those questions were used to guide the development of my interview questions.

Interviews

Interview protocols were designed to encourage the participants to speak freely about their perceptions of using MBLs. The interview questions focused on the following themes:

1) Participants' past experiences using MBLs;
2) Participants' successes and challenges using MBLs;
3) Participants' perceptions of advantages and disadvantages of using MBLs; and,
4) Participants' future plans on using MBLs.

Interviews are principally used in case studies to elicit rich descriptions and interpretations in the participants own words (Bogdan & Biklen, 1992; Yin, 1994). Semi-structured, in-depth interviews were used to explore the perceptions of the stakeholders so that they could describe their perceptions of the process they were experiencing.

I selected participants on the basis of those who volunteered. Interviews with the participant students occurred in the teacher's office adjacent to the classroom. Before interviewing the students, I asked the teacher's permission to release those students from the class for a minimum of thirty minutes.

The interviews were conducted in a semi-structured format allowing the researcher to be flexible in following up the given responses. The focus of the interviews was to learn the students and the teacher's views about using MBLs in the lab and how they affected their lab experiences. I used quotes from students' responses on the MBLAQ as prompt to:

1) Represent their views;
2) Provide evidence to support my interpretation of their ideas; and,
3) Provide context for readers to judge the quality of the interpretation made by the researcher.

Since the students worked in the laboratory in groups of two, I interviewed them as a group. Groups were also selected on the basis of degree of interest in the activity. Paying attention to dynamics the *hermeneutic circle* in this research, I asked the first focus group students to nominate (Guba & Lincoln, 1989) another group who might have a different perception than they had held.

Student Interviews

I conducted two types of interviews with the students. "Room Interviews" were conducted at the office of the teacher adjacent to the classroom. During the "Room Interviews" the office door was closed. In doing so, the students and I had the necessary silence and privacy for the interview process.

I called the second type of interview "On-task Interviews". These interviews were mainly comprised of conversations that the students and I had while they were performing the MBL activity. On task interviews were relatively short. The purpose of these interviews was to better make sense of the challenges students had while they were on task. Following questions were usually used to initiate these conversations:

1) How did you like the MBL collecting data ?
2) Are you having any problems?
3) Do you have previous experience using MBLs?

In order to conduct student "Room" interviews I asked the teacher to release the students from the class for a minimum of 30 minutes. The purpose of the "Room interviews" was to have an in depth understanding of students' perceptions of MBL. In these interviews I wanted students to elaborate on some of the issues that they had indicated during "on task interviews". The questions in "Room interviews" consisted of semi-structured questions some of which included in the "MBL Activity Questionnaire".

In addition to audio-taping the interviews with the focus group students, I also audio taped the conversations that I had with other students while they were on task. These relatively short conversations initiated by either the investigator or the students. The content of these small conversations varied from the subject matter of the experiment to manipulating the MBLs. These conversations provided me with the opportunity to have a better understanding of the common challenges that most of the students' had in using the MBLs.

Observation

I observed the students while they were performing the MBL Activity. The main purpose of this observation was to gain more insight into the difficulties that the students had during the activity. The observations recorded during the laboratory activity and analyzed at a later time. These observations were used to focus on the following points:

1. Students' participations to the activity.
2. Students' interactions during the activity.

I reviewed the observation field notes to develop a series of questions for use during the informal interviews. These questions were used to elicit information regarding the "how" of students' interactions with the MBLs observed in the classroom. Observations also provided evidence to support the assertions made in this investigation

Data Analysis

As suggested by some of the interpretive researchers (Guba & Lincoln, 1989; Yin, 1989; Creswell, 1994) I used coding procedure in order to analyze the data. After I read each transcript and questionnaire responses, I coded each perception or part of perception as to the category it best fit. The coding type for the proposed study was based on the perspectives held by participants and participants' ways of thinking about using MBLs (Bogdan &Biklen, 1992). Coding procedure was used to reduce the information into categories

The interview transcripts and the responses to the MBLAQs were analyzed to reveal the patterns of perceptions. Transcripts and responses to the questionnaire items were read, and any sentence or phrase that related to the students' and the teacher's perception of using MBL was highlighted. Each highlighted sentence or phrase was summarized in one or two words. Based on these summaries perceptions were assigned into five categories. Similarities and differences among the perceptions of the stakeholders were categorized.

Verification

Member checks were conducted to receive feedback and verification from the stakeholders. In the verification process I took the transcripts, organized them and asked subjects whether they agreed with them. After transcribing the interviews and adding my interpretations to each transcript I presented them to them to the participants for their inspection. I wrote a letter as the cover page of the transcriptions. In those letters I encouraged the participants to retract/augment/add to their commentary. I continued doing this process until they are satisfied that their reflections are adequately represented(Guba & Lincoln, 1989).

Ethics of the Research

All of the interviews were guaranteed anonymity. Pseudonyms were used for the students and the teacher. I recorded the stakeholders' responses and returned to each stakeholder with written-up reports of the interviews for verification. Each stakeholder then had the opportunity to change any statement attributed to him/her. Stakeholders were further given the copies of other stakeholders' constructions. The purpose of doing this was to give them the opportunity to modify their comments based on other constructions made by the members of the same community.

Participants volunteered to participate and had the right to withdraw from the study at any time. The identity of all participants is protected and pseudonyms are used in this report to protect confidentiality.

Results

Data from this study suggested that the teacher and most of the students alike valued the MBL activity, enjoyed participating in it and wanted to use MBLs in their future labs. In line with literature findings, almost all of the students in this study believed that MBL lessened the time and labor required for collecting, analyzing and displaying the data. The teacher and 24% of the students who wanted to use MBL also stated that they did not want to use MBL for all labs.

My data suggested that most of the students (91%) wanted to use MBL in their future labs because they thought it is an effective way of collecting, analyzing and displaying the data. The teacher and 24% of the students who wanted to use MBL also stated that they did not want to use MBL for all labs. Almost all of the students in this study believed that MBL lessened the time and labor required for collecting, analyzing and displaying the data.

Students' Main Challenges Using MBLs

Students gave mixed responses to the immediacy of the data. Some students stated that receiving immediate feedback from the MBL reinforced their learning and promoted their engagement with the experiment while others believed that the immediacy of collecting, analyzing and displaying data with MBLs made them struggle to understand what was really going on in the experiment

My data revealed that the class did not build a general consensus about the affect of MBLs on their engagement into the activity. Some of the students indicated that MBL promoted their engagement into the activity while others stated that it inhibited their engagement. Furthermore, students engagement differed at different stages of the MBL activity.

As with Emin, Yasemin thought that better understanding of subject matter would influence the effective use of MBL in the science laboratories.

> Yasemin: We used a radiation probe in physics. I did not understand that either. Our teacher explained how to do it. Ok, push this button and the numbers were there. (On task interview, October 25, 2000)

> Yasemin: ….If I did understand what exactly I was doing in the lab, that would have helped too. If I do not understand what is going on in the lab I do not understand the data collecting. It makes me more confused. (Room interview, October 30, 2000)

In this regard, Friedler, Nachmias & Linn's (1990) reported that familiarity with the subject matter of an MBL experiment increase student learning gains. Students involved in their study used MBLs to understand the relationship between a number of variables in a heating experiment. They found that students score gains found to be increased from 49% to 90% when students performed the a similar heating experiment using MBLs for the second time. They further stated that when new variables introduced to the same heating experiment students' score gains decreased.

Immediacy of Data

Immediacy of Data inhibited some students understanding of subject matter As an example, although Yasemin recognized that processing data with MBLs was faster than doing it with traditional techniques, she stated that she would occasionally prefer doing it by hand with traditional techniques. She thought doing it by hand would save her time "to think" and give her more time to "internalize" what she was doing. She did not feel like the MBL helped her making connections between her pre-existing knowledge and the subject matter of the activity because she felt that gathering data in real time lessened her time to personalize the information.

Moreover, she indicated that gathering data in real time was a lot faster than she needed. Above data suggest that considering the limitations stemming from 50 minutes class period time, MBLs seems to be not suitable for slow learning students

Pre-requisite skills prior to using MBLs

Some students felt like they needed to poses pre-requisite skills prior to using MBLs in their scientific investigations. Ali suggested that using MBLs in investigations might be too complicated for some high school grade levels. He mentioned, for example, (in the case of graphing) that using MBLs might not be a good thing for 9th or 10th grade students because those students might lack the basic skills of graphing, such as not knowing how to plot the graph. He thought that MBLs were more appropriate for advanced classes where students would already have the requisite skills of graphing. He indicated that understanding the MBL-generated graphs was not a problem for him because he had already learnt graphing skills in his Chemistry 1 and mathematics classes. Ali said that, in order to use MBLs more effectively, students should take some other courses to gain the skills necessary to analyze the data. In line with the MBL literature he also called attention to the point that students first had to have sound basic graphing skills in order to benefit more from the MBL generated graphs.

> Ali: For this class I think it[using MBLs in scientific investigations] is good. But I do not think if it was like a Chemistry 1 class, it might not be good because the kids might not have a background. We [Chemistry 2 students] took Chem. 1 so we kind of have a more background in analyzing the data. So, you know it is like in the math class. When you are getting calculus, they do not go over Algebra 1. (Room interview, October 26, 2000)

> Ali: For like the automatic graphing, people might say we should not do this. The kids should first learn the basics. They should not use it in the earlier classes. These are more suitable for later classes. (Room interview, October 26, 2000)

Ali believed that he and most of his friends in the AP Chemistry class had already mastered the basic graphing skills. Therefore, he thought there was nothing wrong with using automatically generated graphs.

Similarly, the teacher also thought that students should not "jump ahead too fast" in using the MBLs. He thought that the students should already possess the skills of using an analog device, like a thermometer, so that they could make sense of what they are doing with MBL.

> Teacher: AP students know how to use an analog device and get the correct precision. They know that already, so why make them do it again. But if they would have got all those thermometer readings done a long time ago in middle school or elementary school, which we do not do enough, then this works great. (Teacher Interview, October 26, 2000)
>
> Teacher: What good is this if a kid cannot even draw a graph? I still have students in 10th and 11th grade that do not get the scaling right. How is that helping them if they cannot draw a graph? You need to make sure that they have got the basics. See, with my CHEM 1 I would not start out with using this. I would start out making them draw graphs and make sure that everybody knows how to draw a graph. Once they know how to draw a graph then we are not going to waste time anymore (Teacher Interview, October 26, 2000).

As seen above statements pertain to data analysis feature of MBLs. The teacher did not support the use of MBLs for all grade levels was teaching. Compared to 10th grade students the teacher found MBLs to be more suitable for 11th grade students as he thought 11th grade students would be more equipped with basic graphing skills. This statement further suggest that effective incorporation of MBLs into science laboratories as to analyzing scientific data is much more related to graphing skills of the students than their school grade level. Therefore, it would not be wrong to claim that the sooner students are furnished with graphing concepts the sooner they can make use of MBLs in their laboratory experiences for data analysis purposes.

Direct Experience with Data

Some of the students I interviewed felt that they were loosing direct experience with the data particularly while the MBL was collecting data. They said they felt like they had nothing to do other than just wait for the numbers come out of the MBL. They thought that they were indirectly dealing with the data, which caused them to feel bored and detached from the experiment.

As with some other students, Yasemin stated that she felt herself detached from the experiment while MBL was collecting data. She felt "passive" and bored to some extent, which influenced her further engagement into the activity.

> Yasemin: You are not really doing whole a lot you are just sticking the probes into orange juice and that is most of the activity that you do of course you also push the on button too. I do not know. Yeah, that was kind of boring. (Room interview, October 26, 2000)
>
> I felt less engaged, waiting instead for the MBL to collect data. (MBL Activity Questionnaire, October 25, 2000)
>
> At first it motivated me to jump right into the lab but then it took so long to complete the data on the calculator that I found myself waiting around. I became a little bored because the calculator was doing all the work. (MBL Activity Questionnaire, October, 25, 2000)

Emin had a somewhat different perspective on the engagement issue. He felt himself disengaged from the activity during some portions of the experiment. Consistent with his earlier statements, he said he felt disengaged at the beginning and then became more engaged through the end of the experiment, specifically during the analysis portion.

Sensitivity of Data Representation

One of the most common issue that the students did not understand about the graphing was the sensitivity of the graphing scale. Most of the students did not appear to understand the way that the MBL displayed the data. They appeared to be lost when they noticed the mismatch of what they were expecting and what the MBL displayed on the screen. As an example, Yasemin had difficulty in making sense of the MBL generated graphs. Contradictory to her observations, the MBL plotted the data as if it changed dramatically during the activity.

> Yasemin: Yeah, the only one thing I found really frustrating with the graph. Because it was like: What is this? What this showing to me? I thought that graph was totally meaningless because it was all about the same number. It was not changing that much I did not really see the purpose of the graph. (Room interview, October 26, 2000)

Some of the students I interviewed stated that even though they did not observe rapid changes in, for instance, the temperature, MBL graphs displayed the data as if there were big, rapid changes within small periods of time. Sensitivity in the display of the data appeared to be the leading cause of misunderstanding. Those students who had problems initially felt comfortable with the graphs when they were told that the fluctuations and rapid changes on the graph was because of the sensitivity of the graphing scale.

While performing the MBL activity students at one station detected a graph anomaly and asked the teacher's help. The graph showing the relationship between the temperature of the orange juice and its pH did not match neither the teacher's nor student's expectations. On the contrary to their expectations, the line resulted from plotting pH against temperature was inversely displayed on the screen. When the student saw the anomaly in the MBL generated graph the following conversation took place between the teacher and the student.

> Teacher: You are right... So, temperature is going down pH is going up. How did you get a graph like this? …It is inverted. In other words, as I go this way… It is backwards. Temperature is going down, while the pH… goes up… which is right but it is backwards. (Classroom Conversation, October 25, 2000)

> Student: Temperature should be on the X axis. (Classroom Conversation, October 25, 2000)

Teacher: Right, so here temperature is going, but it is like… ph is here (x axis) temperature is here. (Classroom Conversation, October 25, 2000)

Student: Right. Temperature should be independent. Temperature should be X. (Classroom Conversation, October 25, 2000)

Teacher: But temperature…. As temperature goes up pH should be going down. Right? (Classroom Conversation, October 25, 2000)

Student: Yeah.

As seen above MBL graph anomaly seemed to facilitate student investigation of the relationship between graph and scientific concept being investigated. However, if it was gone undetected by either the students or the teacher, it might have lead to misinterpretation of the data and thereby misunderstanding of the scientific concept being investigated.

At the time of the experimentation the teacher did not have an explanation for the anomaly in the graph. However, later on, he figured out that the places of the probes should be reversed on the interface. As to function properly, the temperature probe needed be plugged in Channel 1 whereas the pH probe needed to be plugged in Channel 2 of the interface.

Conclusion

Tobin (1997) noted that, "The focus of whole-class activity must be on enhancing the learning of all students..." (p. 386). This study suggested that MBLs do not necessarily promote learning for all students. Some students may need extra help from the teacher in order to grasp the scientific concepts embedded in the MBL activities. Friedler Nachmias & Linn (1990) particularly emphasized the importance of teacher guidance in MBL experiments. They stated that with no guidance and support from the teacher students tend to confuse the relationship between the variables being investigated and thus achieving lower scores. Considerable amount of the students' problems were resolved with only a little help, which allowed them keep going. This study further suggested that special attention should be given to slow paced learners.

Some of the students indicated that they felt themselves doing nothing but waiting for the numbers to come out of the MBL. Data showed that this waiting affected students' engagement to the activity negatively. Jensen (1998) noted that "Challenge is important; too much or too little and students will give up or get bored"(p. 32). The students appeared to be less challenged while the MBL was collecting the data; therefore, they got bored or detached from the activity. Science teachers play a critical role in keeping students attention with the scientific concept being investigated. In order to keep the students actively engaged in the MBL activity it seems necessary that the teacher find effective ways of keeping students intellectually busy. One way of doing that could be asking "What if" questions which will require student thinking and prediction (Friedler, Nachmias & Linn 1990) and thus help them stay on the task.

Although there has been substantial improvements in the MBL technology in the last 10 years students challenges with regard to using MBLs seem to be very similar. As an example, ten years ago students at various levels of schooling had greatly been challenged by MBL generated graphs. They had difficulties particularly with respect to interpreting the graphs and thus understanding the scientific phenomenon embedded d in the MBL activity. Similarly, in my study students felt that they were challenged by MBL generated graphs.

As to lessen students' challenges, in line with the literature, this study suggested that a little teacher push and support is necessary, especially to facilitated students' understanding of the MBL generated graphs. This study further suggested that in an attempt to conduct experiments using MBL more effectively, teachers should constantly be on the look out for graph anomalies that may simply be resulted from misplug of probes into the interface. Because as seen in this study such anomalies can easily lead to students' misinterpretation of data and thus misunderstanding of the scientific concept being investigated. Finally, as with other instructional technologies MBLs alone does not guarantee increased student learning. If not employed appropriately in scientific investigations they may lead to unwanted student achievement outcomes.

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